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JANUARY 1954

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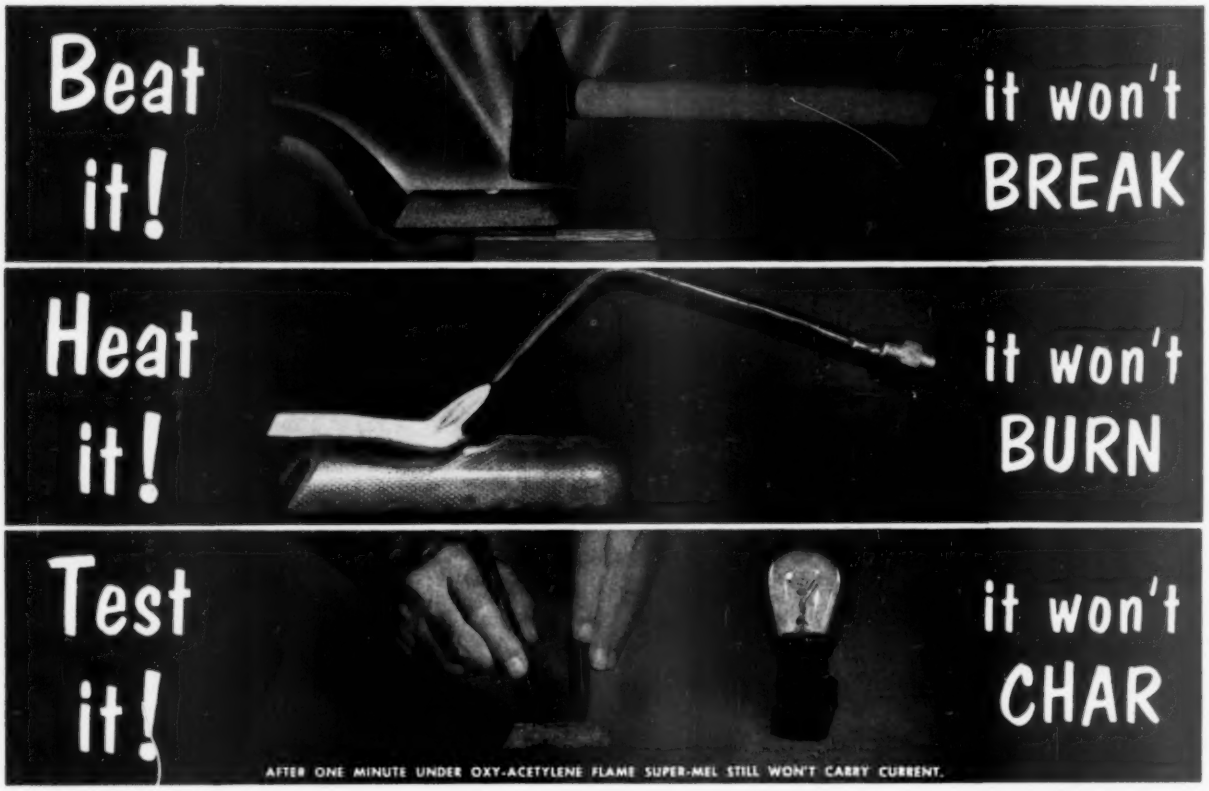

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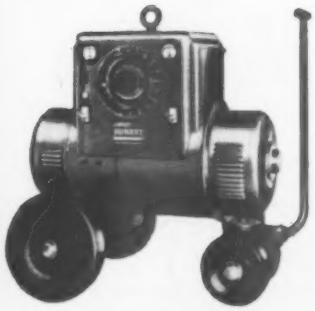

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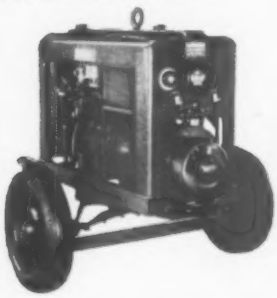

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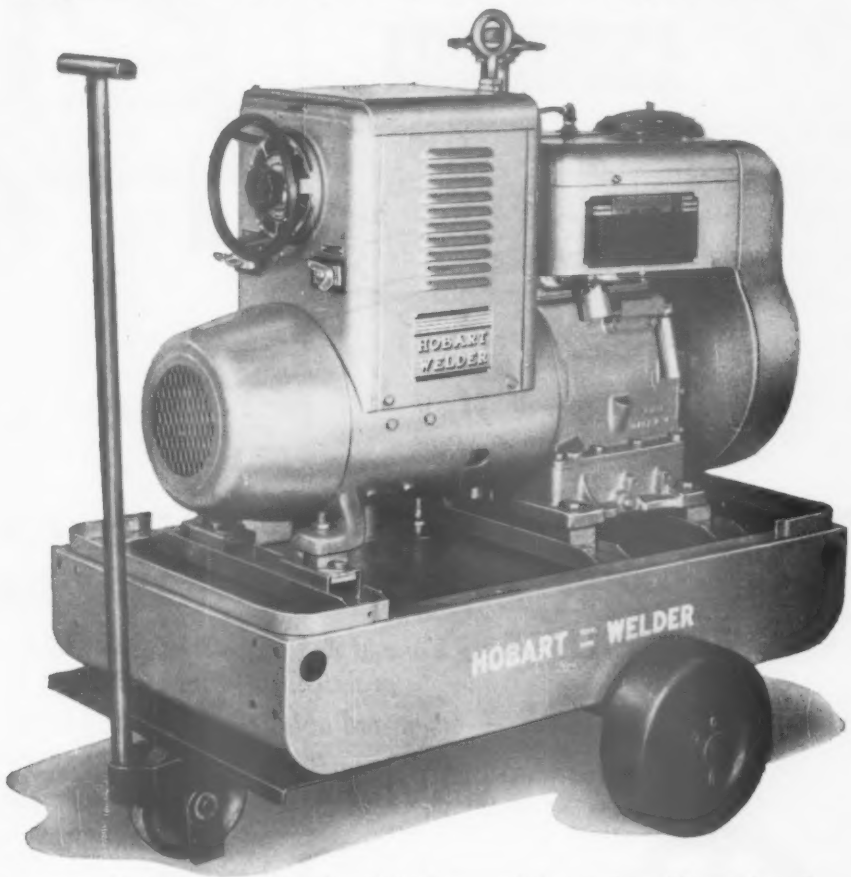

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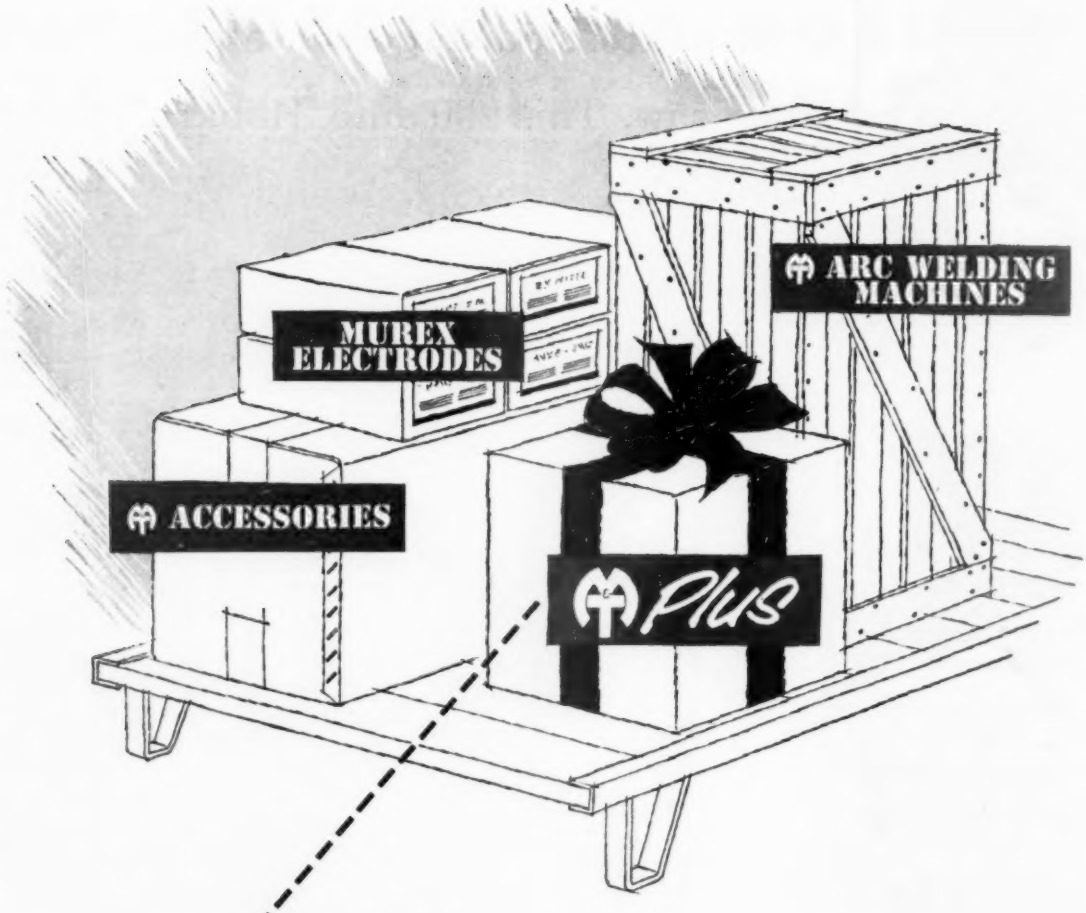

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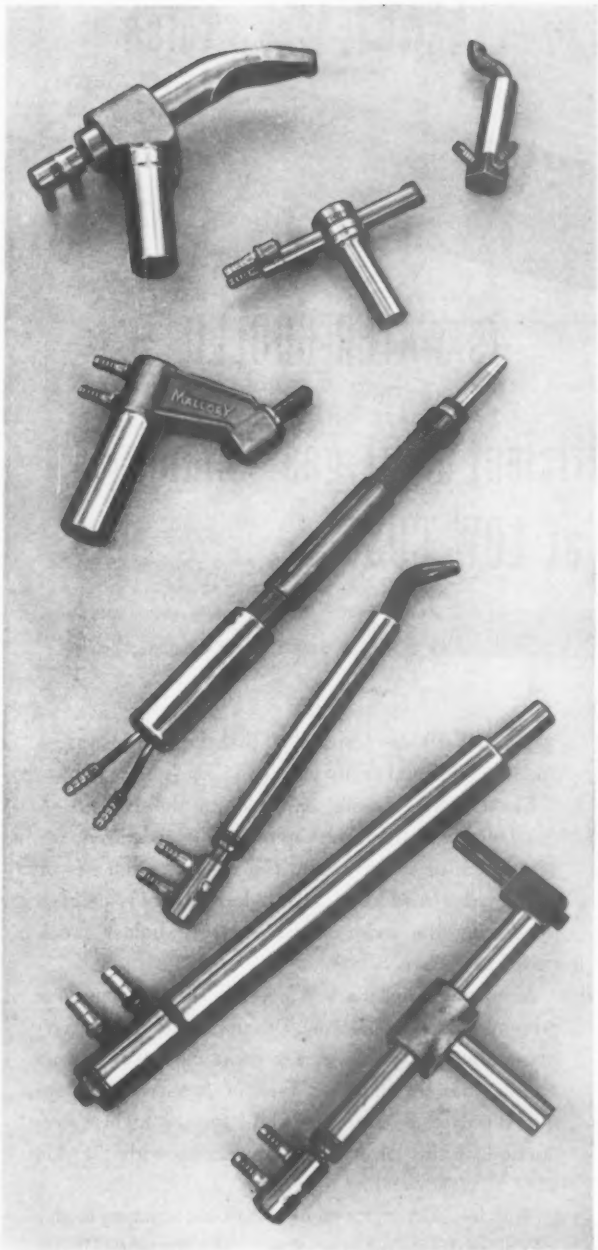

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TECHNICAL PAPERS, ITEMS AND REPORTS

Inert-Gas-Shielded Metal-Arc Welding of Low-Carbon Steels, by G. C. Christopher and R. C. Becker 7
Current Welding Literature 22
1953 Adams Lecture—Aspects of Welding Research in British Merchant Shipbuilding, by R. B. Shepheard 23
Inert-Arc Field Welding of Pressure Piping, by R. T. Pursell 41

PRACTICAL WELDER AND DESIGNER

Faster Fusion, by J. R. Fullerton 47
Welded Bumpers, Profitable Item 51
Rebuilding and Repairing in the Auto Shop, by L. B. Richmann 52
Shaft Repaired in Half the Time at Half the Cost 54

SOCIETY AND RELATED EVENTS

Society News 55
New Literature 71
News of the Industry 74
New Products 79
Section News and Events 86
List of New Members 92
Abstracts of Current Welding Patents .. 94
Index to Advertisers 96

WELDING RESEARCH SUPPLEMENT

Optimum Spot and Seam Welding Conditions for Inconel X, by E. F. Nippes and H. R. Fishman 1-s
An Evaluation of Plastic Analysis as Applied to Structural Design, Discussion by Nicholas J. Hoff 14-s
Ductility Transition of Weld Metal, by W. S. Pellini and E. W. Eschbacher 16-s
Fatigue Strength Butt Joints in 3/8-in. Thick Aluminum Alloy Plates, by E. C. Hartmann, Marshall Holt and I. D. Eaton 21-s
Initiation and Propagation of Brittle Fracture in Structural Steels, Discussion by G. M. Boyd .. 30-s
The Plastic Fatigue Strength of Pressure Vessel Steels, by J. H. Gross, D. E. Gucer and R. D. Stout 31-s
Moisture in Low-Hydrogen Welding Electrodes, by C. DeRop and H. Schmidt-Bach 39-s
An Investigation of Welded Rigid Connections for Portal Frames, by A. A. Toprac 40-s
Discussion by Alfred E. Pearson 56-s
Transformation of Cr-Mo Steels During Welding, by W. R. Apblett, Jr., R. P. Dunphy and W. S. Pellini 57-s
Hot Cracks in Weld Metal, by K. Kautz 64-s

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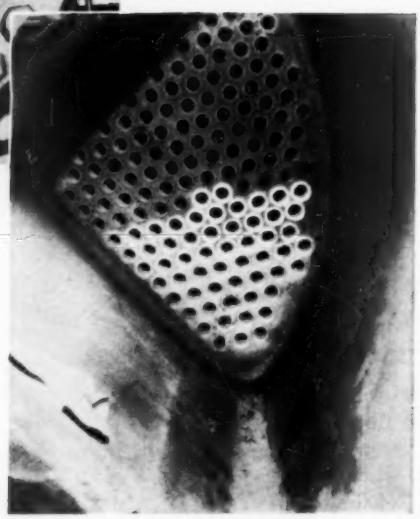

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Inert-Gas-Shielded Metal-Arc Welding of Low-Carbon Steels

Applicability of various types of steel filler wires for the inert-gas-shielded metal-arc welding of low-carbon steels using bead weld tests

by G. C. Christopher and R. C. Becker

INTRODUCTION

AT THE present time the amount of information available concerning the inert-gas-shielded metal-arc welding of low-carbon steel is quite limited. Such lack of basic information concerning welding conditions and procedures has made it quite difficult for fabricators to find practical applications for this process. In addition, sources of suitable welding wires have been quite limited, a condition which does not encourage widespread usage.

An investigation of inert-arc welding of low-carbon steel has been conducted in order to determine information concerning some of the factors which affect the operational characteristics and the weld metal soundness as it will be applied to production usage. The first approach to this welding investigation was made to evaluate the applicability of the various types of steel filler wires available for either the sigma or Aircomatic process. Eleven welding wires were obtained for this investigation from various commercial sources. The tests which were conducted for evaluating these filler wires were made on the basis of their mechanical properties and operational characteristics under typical welding conditions.

In order to explain further the effects of this welding process, single- and multiple-pass bead-weld specimens have been extensively used in testing the suitability of the various filler wires for welding low-carbon steel. The bead-weld test is particularly suitable as it lends itself to definite standardization permitting close control of the variables involved.

Classification of the filler wires into four groups was made, based on their chemical composition to differentiate the soundness of their weld metal deposit and their melt-off characteristics. The melt-off characteristics and chemical composition of the wires were also shown to be interrelated to their electrical resistivity.

The mechanical properties of the welding wires were determined by the use of all-weld-metal tensile tests. Hardness and microscopic examination of the bead-weld specimens indicated the typical microstructure which is formed with the inert-arc welding process.

The effect of the surface preparation used on the steel prior to welding was investigated by using oscillographic recording instruments. The oscillographic measurements were made of the welding arc characteristics as affected by the following surface preparations: (1) sandblasted; (2) as-received; (3) protective coating (red oxide base sealer). This phase was conducted to show how arc stability, which includes such factors as type of metal transfer and change in arc voltage or arc length, is related to weld quality and the degree of skill and effort required by the manual operator.

Throughout this investigation on filler wires, a $^1/_2$-in. thick C-1025, semikilled steel (ASTM Specification A7–50T) was used.

The application of this process to welding $^3/_8$-, $^1/_2$-, and $^5/_8$-in. fillet joints was carried out using $^3/_{32}$-in. filler wires, which is a continuation of a previous investigation[1] on fillet welding conducted with $^1/_{16}$-in. wire.

The apparatus used in performing these various tests on inert-arc welding of low-carbon steel consisted of

G. C. Christopher is Welding Engineer and **R. C. Becker** is Assistant General Supervisor of Welding Research with the International Harvester Co., Manufacturing Research Department, Chicago, Ill.

Presented at the AWS National Fall Meeting, Cleveland, Ohio, Oct. 22, 1953.

manual, semiautomatic units generally referred to as the "Airomatic" or "sigma" equipment.

SCOPE

The filler wires which were investigated for inert-arc welding of low-carbon steel were limited to $^1/_{16}$-in. diam. In the bead-weld test performed, an attempt was made to correlate the chemical composition of the filler wires, in particular the type and amount of deoxidizing elements present, with the welding characteristic and the soundness of the weld metal. The single and multiple bead-weld specimens were given a radiographic examination for porosity and other defects. In addition, metallurgical examination and hardness surveys were carried out on cross sections prepared from each of the single bead-weld specimens.

The variables involved in the welding conditions and procedure were investigated thoroughly so as to obtain information of their flexibility in operation. This primarily consisted of the wire sensitivity to current and voltage changes under an inert gas atmosphere. The investigation of filler wire was made using direct-current reverse polarity on motor generator and rectifier type of welder with argon-plus-oxygen gas mixtures. Limited tests made using straight polarity indicated that more stable welding characteristics and sounder weld deposits are attained with reverse polarity.

A comparative test was made of the gas solubility in weld metal deposited by the inert-arc process, by E-6010 and by E-6015 coated electrodes. There was no attempt made to measure the actual volume or composition of the gases evolved.

The welding tests made, using a $^3/_{32}$-in. welding wire on multiple-pass fillet joints, were carried out primarily to ascertain what advantages in weld speed and soundness could be obtained with a larger diameter welding wire.

PREPARATION OF BEAD-WELD SPECIMENS

Bead-weld specimens were prepared from $^1/_2$-in. thick, semikilled, low-carbon steel plate measuring 3 x 4 in. The surfaces of all bead-weld specimens were sandblasted prior to welding. The sandblasting of the steel specimens was used to obtain a uniform surface condition, eliminating any variable which may be introduced due to mill scale or other oxidation products. Preliminary tests on the as-received steel plate indicated no difficulty in welding with the inert-arc process. To illustrate the effect of other surface conditions, bead-weld specimens were prepared using plate which had been painted with a protective coating (iron oxide base sealer).

CLASSIFICATION OF WELDING WIRES

The chemical analyses of the 11 filler wires and the base metal used in this investigation are contained in Table 1. In order to differentiate the various welding properties, the wires were classified into four groups according to the percent of manganese and silicon found to be present in the wire. These elements, when present in the welding wire, act as deoxidizers in the molten filler metal. Silicon is the prime deoxidizer and serves to protect carbon and other oxidizable additions. Manganese increases the activity of the silicon and aids in the formation of a fluid slag. In the presence of manganese, the silicates resulting from the deoxidization action combine with the manganese to form a complex manganese silicate which readily floats to the surface of the molten weld metal.[2, 3] The presence of these dark patches of silicates on the weld-metal surface is generally indicative of sound, porosity-free weld metal. The purpose of this classification of filler wires to better illustrate the importance of composition as it affects the welding characteristics and the soundness of the deposited weld metal. Table 1 illustrates the categories into which the wires were classified according to their chemical composition.

The first general class, as referred to in this investigation, contains a low manganese and low silicon content. The welding wires which fell in this category contained a manganese range of 0.05–0.50% and a silicon range of 0.01–0.02%. In this group are included two of the welding wires tested which are designated as PAS-10 and WB-7.

The second general class contains a medium manganese and medium silicon content. The welding wires which fell in this category were of the killed steel type

Table 1—Chemical Composition and Classification of the Low-Carbon Steel Filler Wires and Base Plate Material

*Class of filler metal**	*Designation of welding wire*	*Analyses, %*							
		C	*Mn*	*P*	*S*	*Si*	*Cu*	*Ni*	*Cr*
Class I	PAS-10	0.09	0.05	0.010	0.040	0.01	...	...	...
	WB-7	0.08	0.49	0.010	0.055	0.010	...	...	...
Class II	L3	0.11	1.07	0.015	0.025	0.29	...	...	0.33
	A6	0.10	1.38	0.015	0.035	0.29	...	...	...
	PAS-20	0.22	1.18	0.015	0.040	0.31	...	...	...
	RHT	0.21	1.34	0.020	0.030	0.22	...	...	...
Class III	RHM	0.18	1.98	0.015	0.035	0.010	...	...	...
Class IV	A62	0.23	1.37	0.020	0.010	1.59	Mo 0.43	1.80	...
	A67	0.17	1.10	0.025	0.035	0.46	...	...	...
Not classified	A3	0.18	1.20	0.020	0.031	0.18	...	...	...
	R3	0.13	0.70	0.080	0.035	0.20	0.53	0.45	0.61
$^1/_2$-in. steel test material		0.27	0.46	0.010	0.040	0.02	...	...	...

* Class I: Low-manganese, low-silicon. Class II: Medium-manganese, medium-silicon. Class III: High-manganese, low-silicon. Class IV: Medium-manganese, high-silicon.

Table 2—Chemical Composition of the Weld Metals from Low-Carbon Steel Filler Wires

Class of filler metal	Designation of welding wire	Analyses, % C	Mn	P*	S	Si	Cu	Ni	Cr
Class I	PAS-10	0.01	0.02	...	0.025	0.01	...	...	...
	WB-7	0.02	0.23	...	0.030	0.01	...	...	...
Class II	L3	0.05	0.68	...	0.020	0.09	...	...	...
	A6	0.02	1.0	...	0.02	0.19	...	...	...
	PAS-20	0.17	0.92	...	0.02	0.24	...	...	...
	RHT	0.14	0.98	...	0.025	0.15	...	...	...
Class III	RHM	0.14	1.93	...	0.025	0.01	...	...	...
Class IV	A67	0.14	1.05	...	0.02	0.33	...	...	...
Not classified	A3	0.15	0.79	...	0.020	0.11	...	...	...
	R3	0.08	0.52	0.075	0.03	0.14	0.53	0.41	0.61
Class II, Type RHT (straight polarity)		0.08	0.56	...	0.015	0.06	...	...	...

* No analysis was run when the P in the filler wire was less than 0.03%.

containing a manganese range of 1.07–1.38% and a silicon range of 0.22–0.31%. This group consisted of four of the filler wires tested which are designated as L3, A6, PAS-20 and RHT.

The third class of filler wires are those which contain a high manganese and low silicon content. The particular filler wire which was tested from this class, designated RHM, contained a manganese of 1.98% and a silicon content of 0.01%.

The fourth filler wires are those which contain a medium manganese and a relatively high silicon. Two filler wires in this group were tested and are designated A62 and A67. The wires showed a manganese range of 1.10–1.37% and a silicon range of 0.46–1.60%.

The filler wire A3, which had a manganese content of 1.20% and a silicon content of 0.18%, was considered to fall between Classes II and III as a result of the low silicon. The Type R3 filler wire contained alloy additions of 0.41% nickel, 0.61% chromium and 0.53% copper with low manganese (0.70%) and medium silicon (0.20%). This R3 wire was not classified into any of the four groupings and should be considered as preferentially suited only for limited application on low-carbon steel due to the strong tendency for crater cracking when used on low-carbon steel.

EFFICIENCY OF ALLOY TRANSFER

The weld metal deposits from several of the filler wires tested were analyzed in order to determine the amount of alloy constituents lost during welding. The samples of weld deposit used for the chemical analysis were taken from the all-weld-metal tensile specimens so as to eliminate any chance of dilution from the base plate. This procedure would also provide a correlation between the chemical analysis and mechanical properties of the weld metal.

1. Decarburization and Porosity

The chemical analyses of the weld deposits are shown in Table 2. It is interesting to note that the amount of the deoxidizers, manganese and silicon, which is present in the wires is one of the important factors controlling the degree of decarburization. Controlling the degree of decarburization reflects on the amount of porosity which is formed in the weld metal and fusion zone.

The results obtained with the Class I (Type PAS-20 and WB-7) filler wires indicated that as high as 75–80% of the original carbon content is lost during welding. The carbon and sulfur present in the welding wire combines with oxygen to form the gases CO_2 (or CO) and SO_2. These gases, to a larger extent, are entrapped in the weld metal causing porosity. The manganese and silicon were too low to effectively prevent these gas reactions.

Results of analyses on the Class II filler metals revealed that the degree of decarburization varies with the original carbon content and the activity of the silicon and the manganese. The Type L3 and A6 filler wires which had an original carbon content of 0.10% showed a carbon loss of 50 and 80% respectively. This

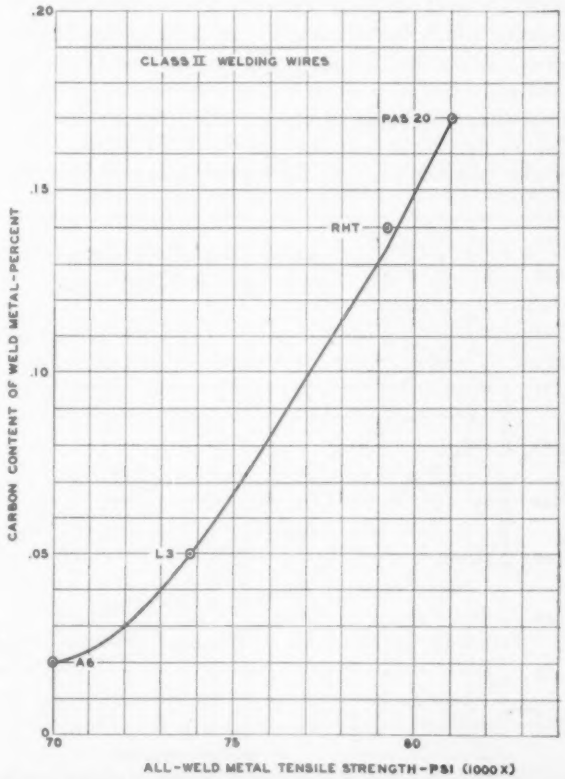


Fig. 1 Weld metal transfer efficiency vs. tensile strength

would indicate that the manganese and silicon in L3 was more active and effective in preventing the oxidation reactions. The manganese and silicon content in these two wires were not of a sufficiently high value to cause the forced deoxidation of the weld metal. This is shown to be the case by the presence of fine porosity in the weld metal when welding on semikilled steel. The results on Type RHT and PAS-20 weld metals indicated that, with an original carbon content of approximately 0.22%, a carbon loss of roughly 24% was obtained. The physical properties of the Class II filler metals are closely correlated to the loss in carbon content as shown from the all-weld-metal tensile tests. The curve in Fig. 1 illustrates the influence of carbon content in the weld metal on the comparative tensile properties of the Class II filler wires.

The Class III filler wire (Type RHM) revealed that the high manganese content (1.98%) in combination with the low silicon (0.01%) was not sufficient to prevent the decarburization reaction which resulted in a 23% loss of the original carbon content.

The important thing to understand from these analyses of weld metal deposits is that no consideration is being made for the reaction of the filler metal and the base metal at the fusion zone. This reaction at the fusion interface will give chemical and physical results which will be entirely different than those which are shown for the undiluted weld metal. The effect of the deoxidizers at the fusion zone will be dependent upon the class of filler wire and grade of steel used. From the welding tests performed it was noted that when using Class II welding wires on semikilled steel the porosity which formed usually initiated at the fusion zone. This condition also held true for the Class III filler wires but to a much higher degree. The Class I filler wires developed porosity both in the weld metal and at the fusion interface of the bead welds. The results with the Class IV filler wires indicated that the porosity in the weld metal was due to the erratic nature of the welding arc rather than the lack of sufficient deoxidizers. Erratic welding arcs cause turbulence in the gas shield allowing nitrogen and oxygen to be entrapped and react with the molten weld metal.

The lowest degree of decarburization (18%) was shown by the Class IV (Type A67) filler wire. The composition of the A-67 filler wire was apparently balanced to the point where the deoxidizing action of silicon and manganese was very effective as compared to the Class II filler wires.

With straight polarity welding in which higher oxygen additions are used in the shielding gas, the degree of decarburization is considerably higher. Results of a chemical analysis of Class II (Type RHT) weld metal indicated a 62% loss of the original carbon content (Table 2). The amount of silicon and manganese present is evidently not sufficient to overcome the higher oxygen content (5–6%) of the shielding gas as well as the erratic action of the welding arc. It would be expected that this higher carbon loss would result in a reduction of the weld metal tensile properties as compared to reverse polarity.

2. *Effect of Oxygen Addition to the Shielding Gas*

Another factor in inert-arc welding of semikilled, low-carbon steels which has a considerable influence on the efficiency of weld metal transferred is the amount of oxygen added to the argon gas shield. In order to illustrate the effect of oxygen in the shielding gas, a Class II welding wire, Type L3, was operated at the same current density with the oxygen content of the shielding gas varying from 0.0 to 10.0%. The results are shown in Fig. 2. Very little loss of carbon resulted until the oxygen content reached 3%.

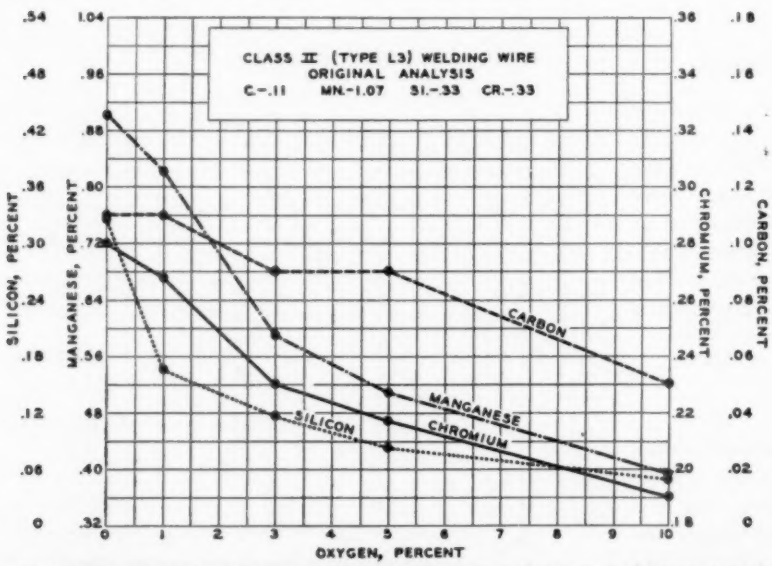


Fig. 2 The efficiency of elements transferred across the inert welding arc with mixtures of oxygen in argon

3. *Alloy Transfer*

The results of the analysis on the Type R3 filler wire which contained three alloy constituents indicated that very little loss of copper, chromium and nickel was occurring using the inert-arc process.

The effect of the oxygen content in the shielding gas on the loss of alloys from Class II, Type L3, welding wire is shown in Fig. 2. As the oxygen content was increased, the chromium loss became greater, reaching 42% with a 10% oxygen content. A 15% chromium loss was obtained with no oxygen present in the shielding gas. The rapid loss of manganese and silicon with increasing oxygen content was evidence of their effectiveness in deoxidation.

BEAD-WELD TESTS

The welding conditions and techniques used in preparing the bead-weld specimens are those which were found most satisfactory for each of the filler wires and are shown in Table 3. The deposition characteristics encountered in the single- and multiple-pass welds, using semikilled steel plate, are indicative of those conditions which may be expected on various types of weld joints in production. The degree of weld soundness is also representative of what might be expected under production conditions.

The investigation of the welding characteristics of each filler wire was twofold; namely (1) the measurement of the welding variables such as weld current, arc voltage, melt-off rate and the gas flow required for proper protection of the weld bead, and (2) the operational factors which were partly dependent on the operator's control and observations made of the weld arc and weld pool such as ease of welding, turbulence of the weld pool, control of bead contour and undercutting, stability of the welding arc as based on the wire's sensitivity to arc length variations, and the effect of angular changes of the electrode.

In practically all the welding tests performed on filler wires, the best and more consistent results could be obtained using the backhand technique. With the forehand technique, however, satisfactory results and quality welds were obtained where less penetration and higher welding speed are necessary and suitable. The particular limitation in using the forehand technique is that it requires a very stable arc which in turn is dependent on current density as well as the type of filler wire being used. In order to operate successfully with the forehand technique, a filler wire must possess arc stability at the higher current densities wherein the metal transfer in the arc is of the commonly called spray type. The erratic arc action which is characteristic of globular or drop transfer, as obtained in reverse polarity at lower current densities, is not satisfactory for use with the forehand technique. The flexibility in the melt-off rate of each filler wire will depend upon their composition and the welding current range within which the wire will operate satisfactorily.

A bead-weld specimen was prepared from each filler wire using a single- and multiple-pass welding procedure. The interpass temperature on the multiple-pass welds was held below 600° F, due to the overheating of the weld metal on the small test specimens. An interpass temperature of 600° F and above resulted in poor bead contour having an oxidized surface appearance. The filler wires in Class I, Class III and the unclassified Type R3 resulted in increased amounts of porosity when operated above 600° F. When the Class II and Class IV filler wires are operated at or above 600° F, no difficulty was encountered in keeping bead soundness; however, difficulty was found in obtaining uniform bead contour on the multiple-pass weld specimens.

The welding speeds used in preparing the filler wire test specimens were adjusted so as to obtain a sound weld deposit. For the Class I and Class III filler metals, it was noted that the smaller the bead welds, the faster the cooling rate, which in turn lessened the turbulence in the weld pool and lowered the amount of porosity present in the deposit. The Class II and Class IV filler wires can be operated satisfactorily at various welding speeds; the size of the weld beads being changed from a small stringer pass to a $^3/_4$-in. weave pass without impairing the soundness of the deposited weld metal.

In addition to the bead-weld tests which were carried out on the sandblasted steel plate, tests were also conducted on steel specimens with the surface being in the as-received condition and painted with a protective sealer. The filler wires used on these test specimens were from the Class II composition and the welding conditions were held the same except for the gas mixture in which the oxygen addition to the argon required slight modification.

WELDING CHARACTERISTICS

The weld conditions which were used with the various filler wires in preparing the bead-weld specimens are shown in Table 3. These conditions should be considered as being within the best operating range of the welding wires, using a semiautomatic, manually controlled welding gun. With completely automatic equipment, a considerable increase in the current density and melt-off rate for each filler wire can be accomplished.

Table 3—Welding Conditions Used to Evaluate Filler Wires

Class of filler metal	*Designation of welding wire*	*Welding current, amp*	*Arc voltage*	*Electrode melt-off rate, ipm*	*Inert gas consumption, cfh*	*Welding speed, ipm*	*Oxygen addition, %*
Class I	PAS-10	240	22	120	30	12.0	4.0
	WB-7	235	26	130	40	9.0	4.0
Class II	L3	300	29	162	30	13.0	3.0
	A6	300	30	160	30	14.6	3.0
	PAS-20	295	28	155	30	16.2	3.0
	RHT	320	31	170	30	15.0	3.0
Class III	RHM	275	29	140	35	17.0	4.0
Class IV	A62	350	34	260	30	16.0	2.0
	A67	310	35	190	25	14.0	0.0
Not classified	A3	290	28	150	25	14.0	3.0
	R3	285	30	145	30	13.0	4.0

Table 4—Arc Characteristics of Steel Welding Wires

Class of filler metal	*Designation of welding wire*	*Arc stability*	*Type metal transfer*	*Current density, amp/sq in.*	*Welding technique**	*Average deposition rate, lb/hr*
Class I	PAS-10	Very erratic	Drop	78,300	B	6.0
	WB-7	Erratic	Drop	75,000	B	6.5
Class II	L3	Good	Spray	98,000	B-F	8.0
	A6	Good	Spray	98,000	B-F	8.0
	PAS-20	Good	Spray	95,000	B-F	7.5
	RHT	Good	Spray	104,200	B-F	8.5
Class III	RHM	Slightly erratic	Drop	89,800	B	6.5
Class IV	A62	Good	Spray	111,000	B-F	13.0
	A67	Fair	Spray	101,000	B-F	9.5
Not classified	A3	Fair	Spray	94,500	B-F	7.5
	R3	Fair	Spray	91,400	B	7.3

* B—Indicates backhand welding. F—Indicates forehand welding.

1. Porosity vs. Current Density

A comparative analysis of the welding characteristics of the filler wires is shown in Table 4. From this comparison it is clear that the arc stability is closely related to the current density at which the wire operates and the type of metal transfer occurring in the welding arc. The Class I filler wires, which operate at a low current density (75,000 to 78,300 amp/sq in.), exhibit very erratic welding characteristics. The Class II and III filler wires operate at a higher current density (95,000 to 125,000 amp/sq in.) and generally exhibit a stable arc and good welding characteristics.

The Class I filler wires (WB-7 and PAS-10) have an unstable welding arc and produce porous welds under all conditions of testing on semikilled steel. Increasing the current density to approximately 100,000 amp/sq in. resulted in excessive spatter and coarse porosity in the weld metal. Lowering the current density to 75,000 amp/sq in. slightly improved the weld metal soundness but, due to the type of metal transfer obtained (drop or globular), the arc became very erratic. The weld metal remained porous with both the high- and low-current densities. Increasing the shielding gas (argon) flow from 30 to 60 cfh showed no significant improvement in the weld soundness. However, increasing the oxygen content of the shielding gas from 1 to 6% reduced the spattering and tended to stabilize the welding arc, particularly when operating at low-current densities.

The Class II filler wires were found to operate satisfactorily at slightly higher current densities (95,000 to 104,000 amp/sq in.) and generally produced porosity-free welds. Observations of the molten weld pool showed that no turbulence or boiling occurred and that slight variations in the arc length ($^5/_{32}$ to $^1/_4$ in.) causes little effect on the arc stability. However, a longer arc length causes a change in the bead contour which is immediately noticeable.

The Class III filler wire operated best at a current density of 89,800 amp/sq in. and possessed welding characteristics which were considered unsatisfactory. The weld deposit contained excessive porosity. As the current density was increased, the weld pool became very turbulent and the degree of porosity became worse. It was impossible to operate this filler wire at current densities high enough to obtain spray transfer. Weld porosity also was obtained at lower current densities.

The Class IV filler wires operated satisfactory at the highest current densities (101,000 to 111,000 am/sq in.) of all the wires tested and generally showed very stable arc characteristics. However, due to the surface condition of the A-67 filler wire, some erratic arc action was experienced. This erratic arc action apparently causes porosity to be developed.

The unclassified A3 and R3 filler wires operated satisfactorily in the current density range of 91,000 to 95,000 amp/sq in. The soundness of the A3 weld metal was found to be much better than the weld metal obtained from the Class I and III filler wires; however, the consistency of the weld quality was lower than that obtained with the Class II filler wires. The R3 filler wire showed a tendency for crater cracking when used for welding semikilled steel. The arc stability was similar to the Class III filler wire but the porosity level was lower. Increasing the current density above 91,400

Table 5—Relative Amount of Porosity Found in Single- and Multiple-Pass Test Specimens

Class of filler metal	*Designation of welding wire*	*Single-pass weld**	*Multiple-pass weld**	*Type of porosity*
Class I	PAS-10	Numerous	Numerous	Coarse, herringbone
	WB-7	Numerous	Numerous	Coarse, herringbone
Class II	L3	None	4	Fine porosity†
	A6	None	1	Fine porosity†
	PAS-20	None	3	Fine porosity†
	RHT	None	2	Fine porosity†
Class III	RHM	Numerous	Numerous	Coarse porosity
Class IV	A62	None	None	None
	A67	3	6	Coarse and sporadic
Not classified	A3	2	1	Fine porosity†
	R3‡	4	6	Coarse porosity

* Approximate number of porosity defects noted per 3 inch of bead-weld.
† Fine porosity which was present was limited mostly to the start and end of the bead welds.
‡ Radiographic of R3 showed crater cracks to be present.

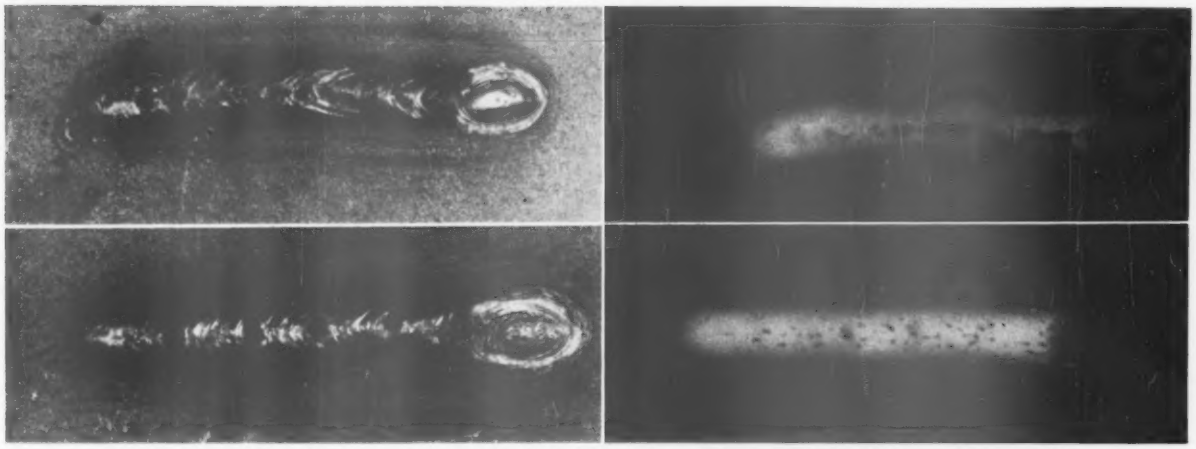


Fig. 3 Typical results obtained with the Class I filler wires for inert-gas-shielded metal-arc welding

amp/sq in. resulted in a turbulent weld pool and porosity.

2. *Porosity and Bead-Weld Appearance*

The visual and radiographic examination of the single- and multiple-pass weld specimens indicated that the degree of porosity and weld appearance is primarily dependent on the following two factors:

(*a*) The composition of the filler wire.
(*b*) The grade or type of steel being welded.[6]

The results of the radiographic examination of single- and multiple-pass weld specimens are shown in Table 5. The several classes are graded as to the degree and type of porosity present in the bead welds.

The surface appearance of the bead-weld specimens

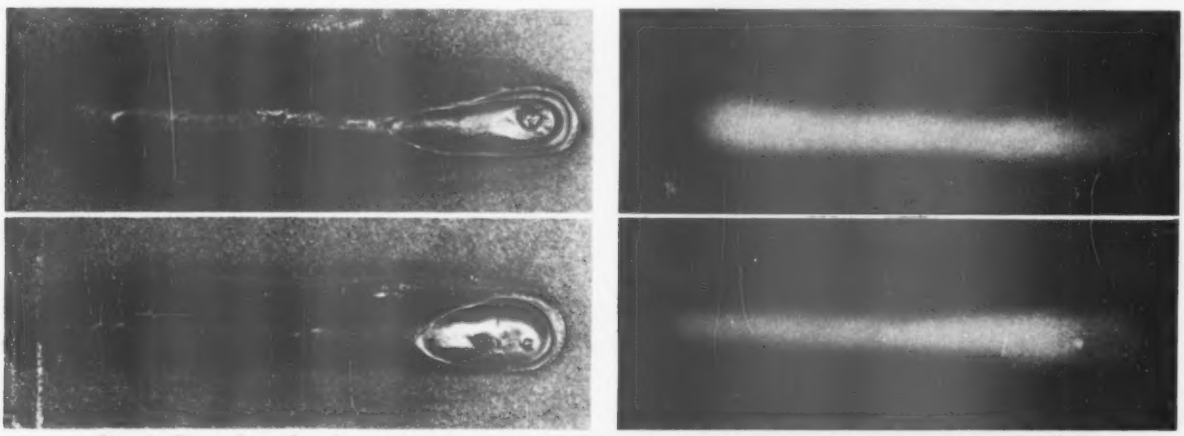


Fig. 4 Typical results obtained with the Class II filler wires for inert-gas-shielded metal-arc welding

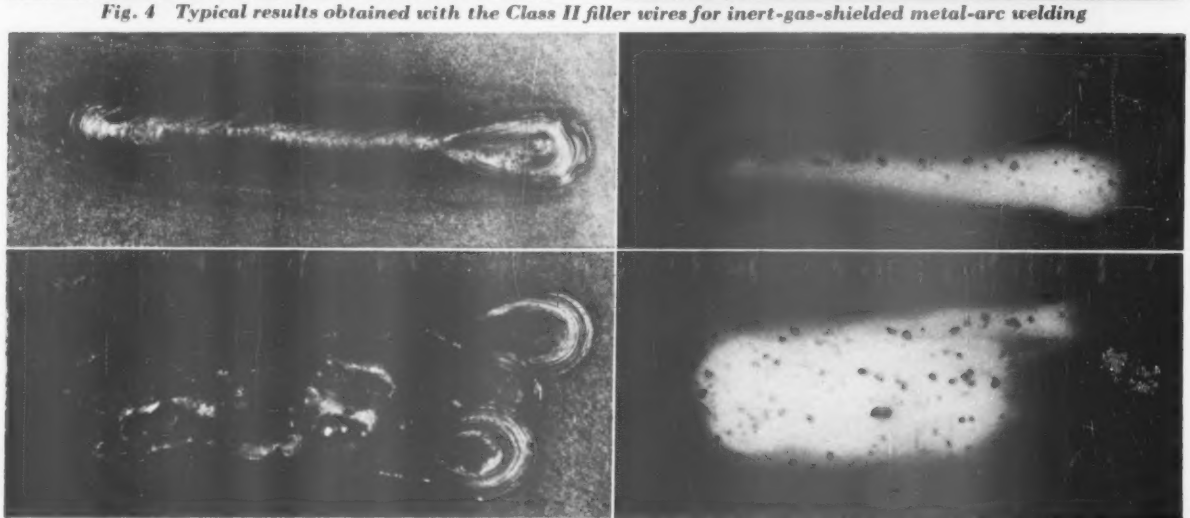


Fig. 5 Typical results obtained with the Class III filler wires for inert-gas-shielded metal-arc welding

and the amount of porosity present in the Class I (WB-7 and PAS-10) filler wires are shown in Fig. 3. It is interesting to note that the herringbone-type porosity pattern and pitting is typical of these weld deposits. The sulfur content of these wires ranged from 0.04–0.055% which, according to Fast,[4] can cause porosity by poisoning the liquid-solid interface in the weld, thereby delaying the gas evolution to a point where voids or porosity are produced.

The Class II (RHT and PAS-20) filler wires revealed the least amount of porosity and had good bead-weld appearance as is shown in Fig. 4. Fine porosity would occasionally result at the start and end of the bead welds. This porosity condition perhaps may be explained by the turbulence which is developed in the gas shield due to the mechanism of starting the arc and to the manipulation of the welding gun by the operator when finishing the weld.

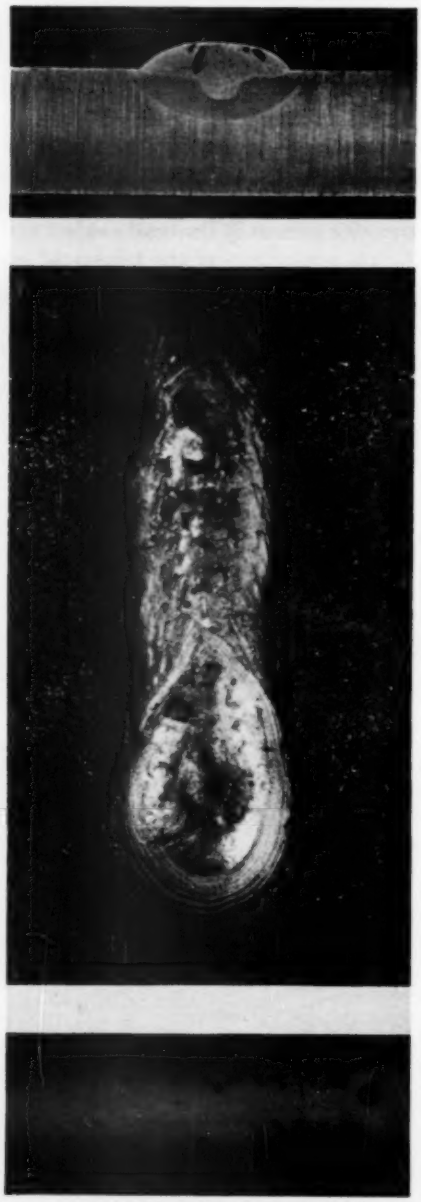


Fig. 6 Typical results obtained with the Class IV, Type A67 filler wire

With the Class III (RHM) filler wire, a coarse, lineal porosity pattern was formed in the bead-weld specimen as depicted in Fig. 5. The appearance of the bead weld is better than that experienced with the Class I weld deposits but the degree of porosity is quite similar.

The results obtained with the Class IV (A67) filler wire indicated that the sporadic, coarse porosity present in the bead weld coincided with the erratic or pulsating action of the welding arc. This type of porosity is illustrated in Fig. 6. With the proper surface cleaning and protection of the Type A67 filler wire, it is believed that the instability of the welding arc would be alleviated. The Type A62 filler wire gave a sound bead-weld on radiographic examination.

X-ray examination of the Type R3 bead-weld specimens indicated that crater cracking was occurring. This cracking may be attributed to the greater amount of alloys present in the weld metal. Similar crater cracking was experienced with the A62 filler wire.

3. Deposition Rates

The deposition rates of the Class I and III filler wires, as shown in Table 4, are the lowest of the several filler wires tested (6 to 6.5 lb/hr). The deposition rates of the Class II and IV filler wires are much higher, ranging from 7.5 to 13 lb/hr. It is interesting to note the difference in deposition rates exhibited by the Class IV filler wires. The Type A67 filler wire, when operating in a current range of 290 to 350 amp, shows a deposition rate of 8 to 10 lb/hr. The Type A62 filler wire, when operating in the same current range, shows a deposition rate of 10 to 15 lb/hr. No explanation has been found for this difference.

4. Electrical Resistivity

Welding with current densities ranging from 90,000 to 130,000 amp/sq in. ($^1/_{16}$-in. wire) requires the use of a high wire feed (100 to 400 ipm). It is, therefore, believed that the electrical conductivity of the filler wires would be an important factor as related to their welding characteristics. Resistivity measurements, which were made of the various filler wires, indicated that a relationship existed between their deposition

Table 6—Electrical Resistance vs. Deposition Rates

Type and class of filler wire	*Electrical resistance, ohm/in.*	*Deposition rate, lb/hr*	*Current range, amp*
Class I			
WB-7	0.00177	5–6.5	230–260
PAS-10	0.00141		
Class II			
A6	0.00295	7–10	300–380
L3	0.00298		
Class III			
RHM	0.00270	7.0–7.5	275–290
Class IV			
Type A67	0.00326	8–15	300–350
Type A62	0.00560		

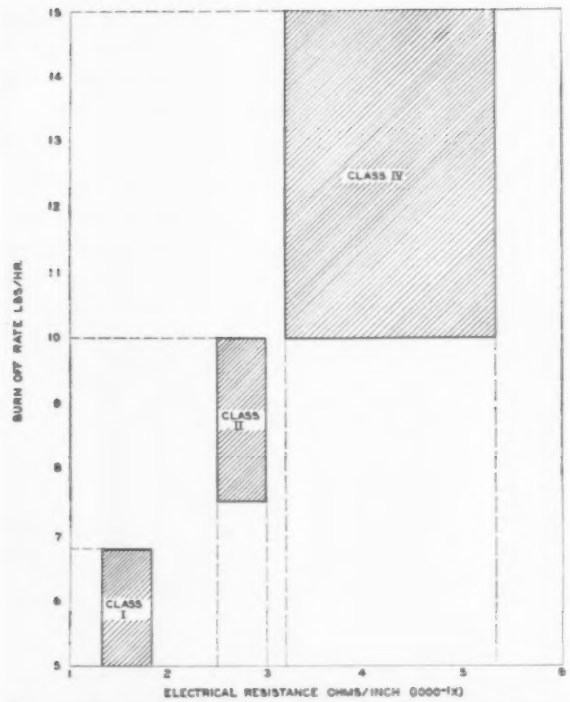


Fig. 7 The general effect of the welding wire's electrical resistance on burn-off characteristics

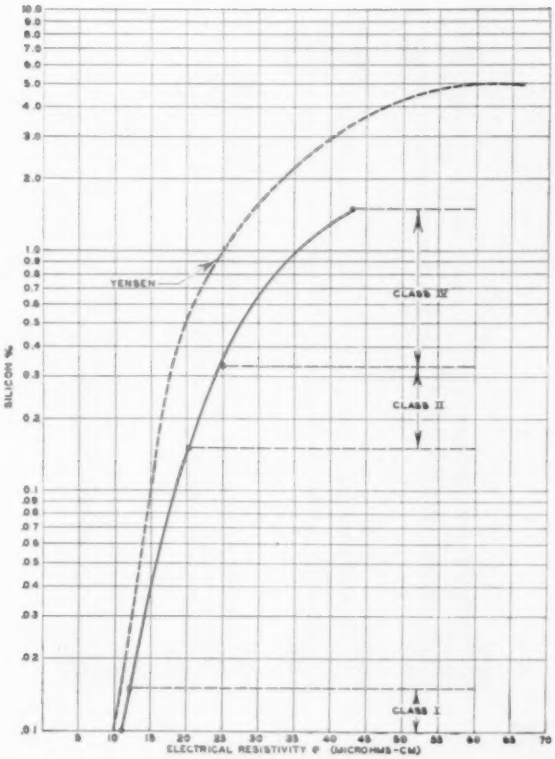


Fig. 8 Electrical Resistivity vs. Silicon Content for Class I, II and IV Welding Wires

rates and electrical resistance. Table 6 shows this relationship.

From Table 6 it is evident that the higher the electrical resistance, the higher the deposition rate of the filler wires when operated at their optimum current density. Figure 7 illustrates the general relationship between the electrical resistance and the burn-off characteristics of three classes of filler wires. Since it was impractical to operate the filler wires outside of their optimum current densities in order to eliminate the current effect variable, no attempt is being made at this time to present other than general trends. In Fig. 8 an attempt has been made to show the correlation between the silicon content of the Class I, II and IV filler wires and their electrical resistivity. This agrees quite closely with the work of Yensen.[5]

5. *Straight Polarity*

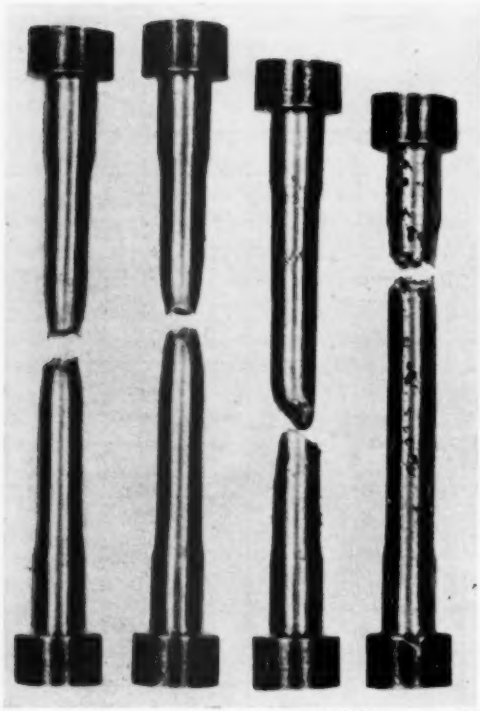
In using straight polarity for inert-arc welding of low-carbon steel, considerably different welding characteristics and conditions are experienced as compared to using reverse polarity. The filler metal is transferred in the welding arc by globulars or drops of metal rather than by the fine spray which is characteristic of reverse polarity welding. As a result of this condition, straight polarity welding does not have the stable arc welding characteristics of reverse polarity. In order to obtain a reasonable degree of stability with straight polarity, it is necessary to use a high current density (115,000 to 160,000 amp/sq in.) with an increase in the oxygen addition to the argon gas shield to about 5–6%. This oxygen content is considerably higher than that used with reverse polarity. When operating at these high-current densities, the deposition rate is much higher than that obtained with reverse polarity, ranging from approximately 15 to 21 lb/hr.

The weld metal deposited with straight polarity, however, does not have the clean quality and smooth bead contour as compared to reverse polarity. An explanation for this condition may be attributed to the higher oxygen content of the shielding gas and the erratic nature of the arc. The higher the amount of carbon present in the filler wire, the more pronounced is the spatter.

Straight polarity welding is useful for welding light gage steel or for build-up applications where weld metal dilution should be kept to a minimum. Such applications take advantage of the reduced penetration obtained with straight polarity. Another advantage in using straight polarity is that it overcomes the undercutting tendency of the inert-arc process. This undercutting tendency is quite noticeable when using reverse polarity.

ALL-WELD-METAL TENSILE TESTS

In order to evaluate the mechanical properties of the filler wires, all-weld-metal tensile specimens were prepared. The method which was used in preparing these specimens was such that the weld metal was deposited between copper dams on a mild steel backing plate. The welding procedure which was found most satisfac-



Type	L3	A6	RHM	WB7
Class	II	II	III	I

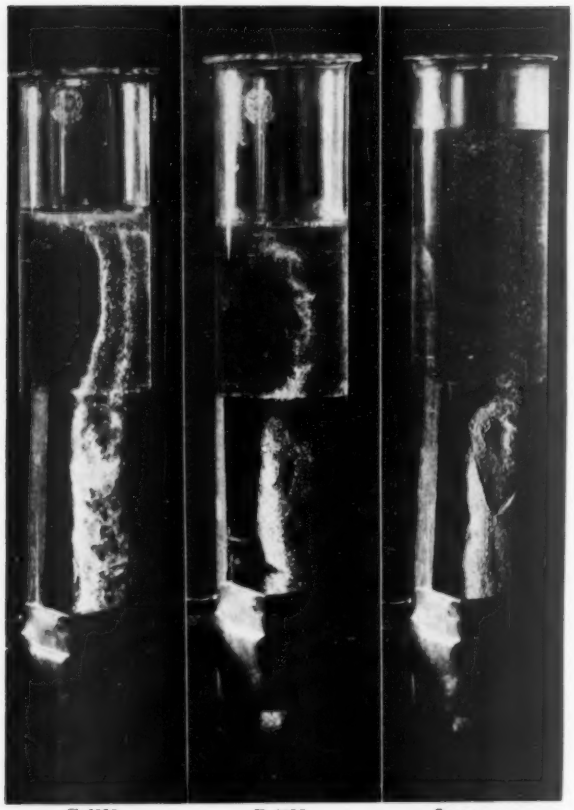
Class	Type	Tensile strength	E, %
Class I	WB7	34,000	13.0
Class II	A6	70,000	31.5
	L3	73,800	20.0
Class III	RHM	78,500	14.0

Fig. 9 Comparative results of all-weld metal tensile test on Class I, II and III filler wire

tory for obtaining the amount of build-up required was reverse polarity with the backhand technique. The interpass temperature was held below 600° F. It was noted that some of the Class I and III filler metals develop porosity when overheated. Apparently, overheating tends to increase the gas formation reactions in the weld metal. Whenever porosity develops in a weld pass, it is necessary to remove it by grinding or chipping before proceeding with the next pass. In the preparation of tensile specimens with the Class I (WB-7 and PAS-10) filler wires, their poor welding stability prevented the obtaining of a sound, all-weld-metal tensile specimen.

Table 7—Comparative Tensile Properties

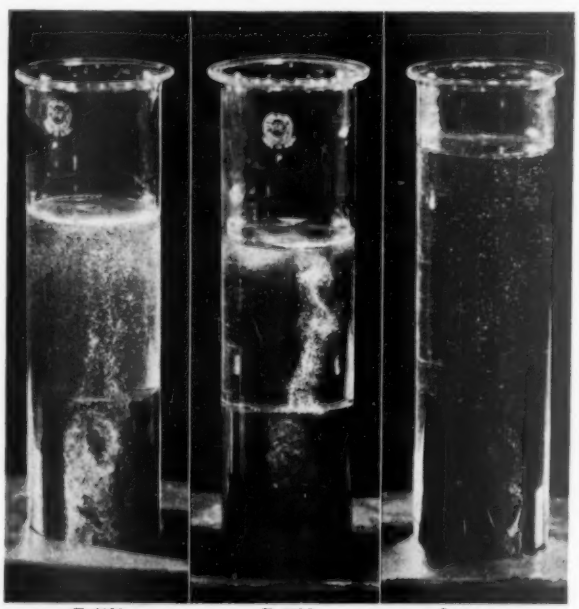
Class of filler metal	*Designation of welding wire*	*Yield strength, psi*	*Ultimate strength, psi*	*% Elongation, 2 in. gage length*
Class I	PAS-10	36,250	40,200	6.0
	WB-7	29,650	34,250	13.0
Class II	L3	61,600	73,800	20.0
	A6	58,200	70,000	31.5
	PAS-20	63,400	81,000	21.0
	RHT	61,200	79,200	30.0
Class III	RHM	66,000	78,500	14.0
Class IV	A62	127,000	148,000	18.0
	A67	55,200	72,000	31.0
Not classified	A3	78,200	93,500	20
	R3	74,300	83,750	5.5



E-6010 E-6015 Inert arc Class II

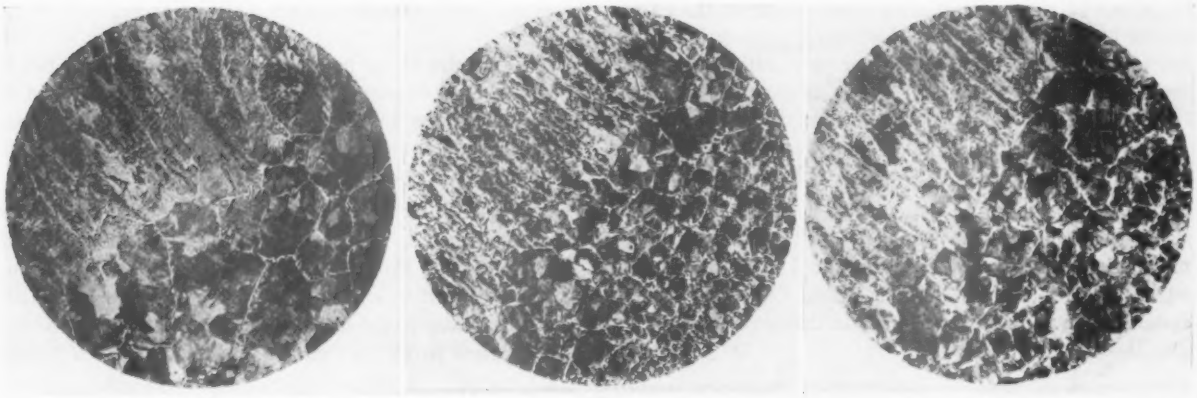
Fig. 10 Comparative quantity of gases evolved from the weld beads after 2 min immersion in glycerin

Figure 9 illustrates the comparative soundness and ductility of Class I, II and III all-weld-metal tensile specimens. The excessive porosity which was encoun-



E-6010 E-6015 Inert arc Class II

Fig. 11 Comparative quantity of gases evolved from the weld beads after 20 min immersion in glycerin



(*A*) (*B*) (*C*)

(*A*) Fusion zone of Class II (Type A6) filler wire. (*B*) Fusion zone of Class II (Type RHT) filler wire. (*C*) Fusion zone of Class II (Type PAS-20) filler wire.

Fig. 12 Typical micrographs of the fusion zone in the Class II filler wires on semikilled low-carbon steel. Nital etch, 2%. × 65

tered with the Class I filler wires, plus its effect on the tensile strength, can be clearly seen.

The results of the all-weld-metal tensile tests are shown in Table 7. It is evident that all of the filler wires tested, with the exception of the Class I wires, have a tensile strength in excess of 70,000 psi. These higher tensile properties can, in part, be attributed to the refining and alloying action of the relatively high manganese and silicon content of the filler wires.

GAS SOLUBILITY IN WELD METAL

A comparative test was made of the amount of dissolved gas present in the weld metal obtained using the inert-arc welding process, E-6010 and E-6015 electrodes. The test method employed to determine the amount of gas evolved was according to the procedure set up in AWS-ASTM Specification A2 33–48T using the glycerin test. However, no attempt was made to measure the actual volume of the gases given off nor their analysis. For illustrating the quantity of gas which is evolved with these three electrodes, pictures were taken at various time intervals after immersion in a glycerin-filled test tube. Figures 10 and 11 illustrate the comparative volumes of gases which are evolved from the bead-weld specimens after 2- and after 30-min immersion in glycerin. It is quite evident that the inert-arc specimen evolved the lowest amount of gases.

MICROSTRUCTURE AND PENETRATION

Figure 12 illustrates the typical fusion zone found with the Class II filler wires. The variation in grain size obtained in the heat-affected zone of the base metal is not unusual, as the welding conditions and the manual operation of the welding gun was not a constant factor in all of these tests.

Since the current density with which the various welding wires operated satisfactorily cover such a wide range, it would be expected that a difference in the amount of fusion and penetration would result. Figure 13 illustrates a comparison between the Class I, II and IV filler wires as to weld penetration and bead contour. The narrow but deep penetration, characteristic of reverse polarity welding in an argon atmosphere, is obtained with the Class II (PAS-20 and A6) and IV (A6-2) filler wires. With the Class I filler wires (WB-7 and PAS-10), this type of nose penetration is less pronounced. Porosity is also noticeable.

The heat affect produced by straight polarity welding with Type RHT filler wire indicates that the penetration obtained (Fig. 13) is concentrated directly below the welding arc with poor fusion along the edges of the bead. The magnification of the photomacrograph of

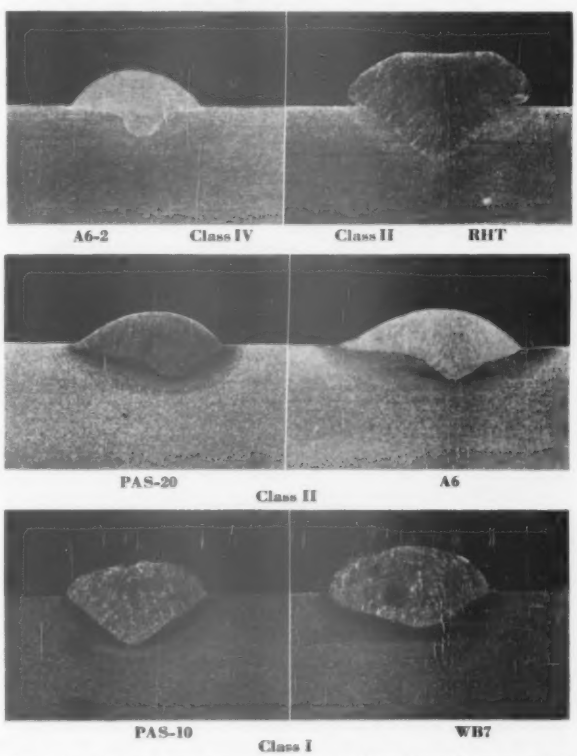


Fig. 13 Typical macrographs of the bead-weld specimens of the class I, II and IV filler wires

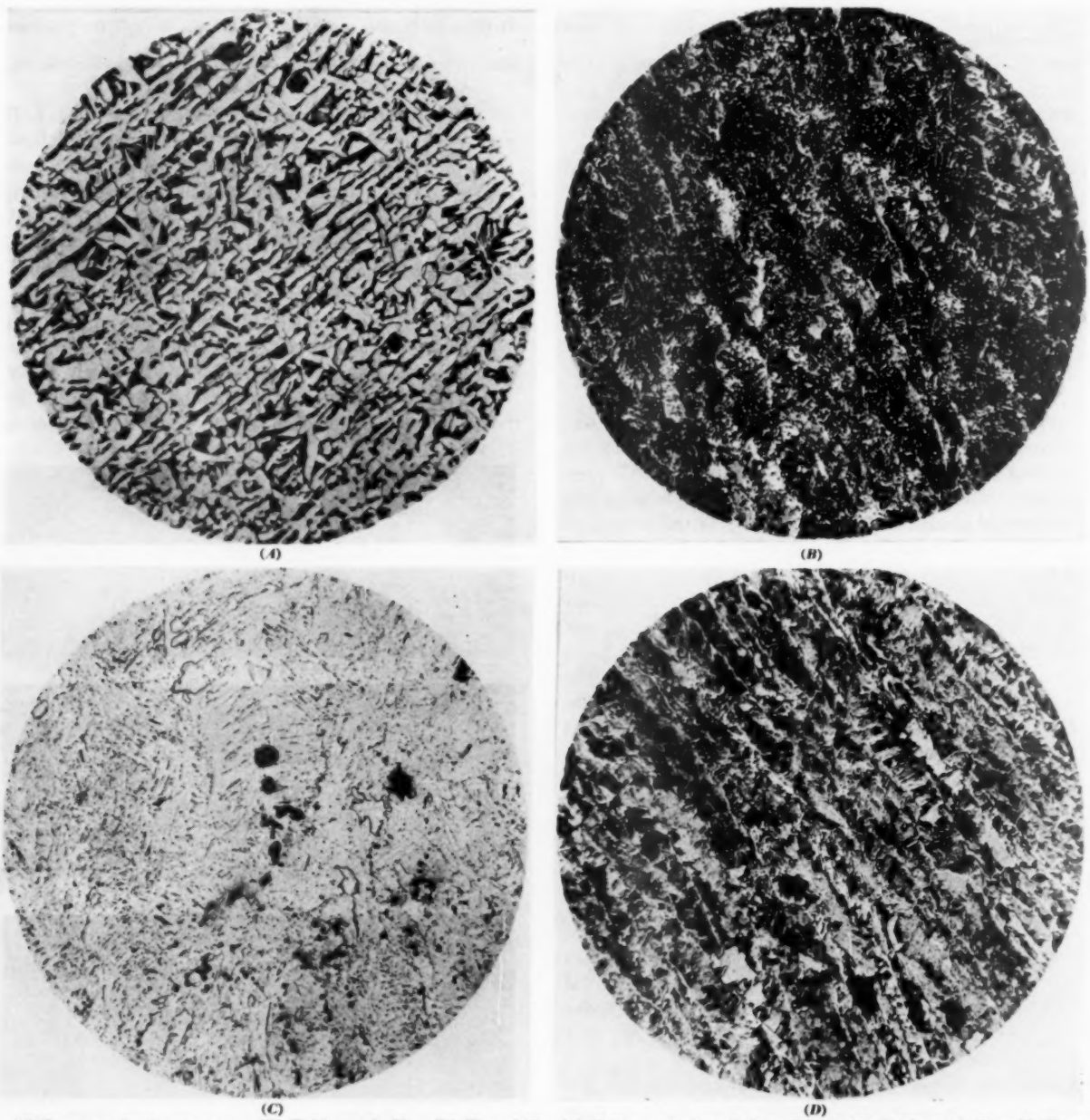
the Class II, Type RHT weld bead is higher than the others in Fig. 13. Taking this into consideration, the macrosection illustrates the lower penetration and the greater weld-bead build up which is characteristic of straight polarity welding.

Figure 14 illustrates the typical weld metal microstructure of a Class I filler wire (WB-7) which shows porosity. This can be compared to the sound weld metal structure of the Class II (RHT) and IV (A67) filler wires. The typical base metal microstructure which was found in the $^1/_2$-in. thick, C-1025 (ASTM Specification A7–50T) steel used in this investigation is also shown.

HARDNESS SURVEY

The results of the hardness explorations on the bead-weld test specimens prepared for the various classes of filler wires are tabulated in Table 8. The hardness measurements were made using a Vickers Hardness Tester with a 50-kg load.

Another interesting feature of this welding process which was noted in this investigation was the apparent higher cooling rate of the weld metal deposit as compared to electric arc welding. The manner in which cooling takes place has a profound influence on the mechanical properties of the weld metal. No actual



(A) Base metal microstructure. (B) Weld metal, Class IV (Type A67). (C) Weld metal, Class I (Type WB-7). (D) Weld metal, Class II (Type RHT).

Fig. 14 Typical micrographs of the base metal and weld metal from Class I, II and IV filler wires. Nital etch, 2%. × 100

Table 8—Hardness Survey of Bead-Weld Specimens*

Class of filler metal	Designation of welding wire	Weld metal		Heat-affected zone		Base metal	
		Avg	Range	Avg	Range	Avg	Range
Class I	PAS-10	150	135–165	200	184–210	158	149–169
	WB-7	141	127–155	206	194–234	158	143–190
Class II	L3	218	195–231	231	228–234	166	143–169
	A6	224	224–239	215	215–216	146	139–154
	PAS-20	235	231–239	247	239–255	155	155–156
	RHT	224	213–236	233	223–244	160	137–173
Class III	RHM	244	236–252	255	224–285	162	152–167
Class IV	A62	289	279–300	310	280–340	165	150–170
	A67	260	250–270	272	260–284	160	155–175
Not classified	A3	242	240–244	271	266–276	158	150–156
	R3	246	240–252	259	253–266	156	155–158

* Vicker Hardness Test using 50-kg. load.

cooling rates were determined; however, it is felt that the lack of the slag coating which is present in the electric arc-welding process increases the cooling rate as the heat losses due to conduction and convection are supplemented by radiation losses. The effective influence of this increased cooling rate will be more significant when using a hardenable weld wire or when welding a hardenable steel.

SURFACE PREPARATION

Welding tests were performed on semikilled, low-carbon steel with surface conditions other than sandblasted. Welds made on as-received samples, the surface of which contained mill scale, as well as samples painted with a protective coating (iron oxide base sealer) indicated that satisfactory weld soundness could be accomplished with slight modifications in the welding conditions.

Class II filler wires were used in the study to determine the effect of surface preparations on welding characteristics.

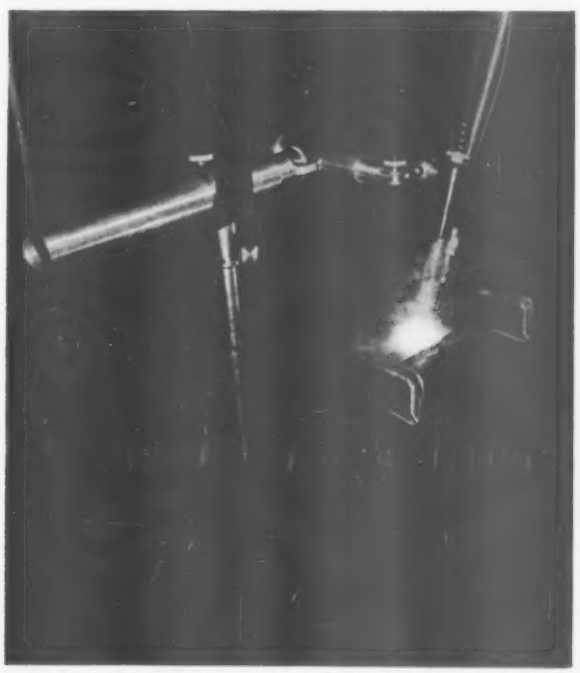
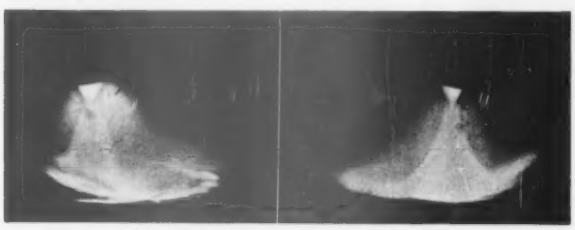


Fig. 15 Welding apparatus used for oscillographic measurements of arc characteristics

The results of the welding test on steel specimens containing mill scale (as-received) were satisfactory provided that the oxygen content of the shielding gas was held to 1.5% or less. The type RHT filler wire was used for this test. Increasing the oxygen addition to the shielding gas above 1.5% resulted in a thin film of oxide appearing on the surface and an irregular surface contour of the weld bead. It is apparent that the mill scale present on the steel surface affects the welding arc in the same manner as oxygen additions to the shielding gas, being approximated equivalent to 3–4% oxygen.

Photographs were taken of the welding arc to illustrate the effect of using a low- and high-current density in obtaining spray and globular metal transfer. The low-current density welding arc (below 80,000 amp/sq in.) produces a globular or drop-type metal transfer and is shown in Fig. 16*A*. The high-current density (above 90,000 amp/sq in.) welding arc produces a spray-type metal transfer which has a very stiff and forceful arc stream. This spray-type metal transfer is typical of good inert-arc welding characteristics and is shown in Fig. 16*B*. With the higher current density welding arc the end of the electrode has a characteristic sharp point, whereas with the lower current density welding arc a round drop of metal is formed at the end of the electrode prior to being transferred across the arc.

In order to graphically show what influence surface preparation has on the welding characteristic, oscillographic records were taken of the arc voltage fluctuation using a Westinghouse, Type PA, magnetic oscillograph. The procedure followed consisted of placing the welding gun in a stationery fixture so as to eliminate the operator variables. The steel test specimen, which



(*A*) (*B*)

(*A*) Low-current density welding arc which depicts globular metal transfer. (*B*) High-current density welding arc which depicts the spray-type metal transfer.

Fig. 16 Photographs of the welding arc showing globular (or drop) and spray-type metal transfer

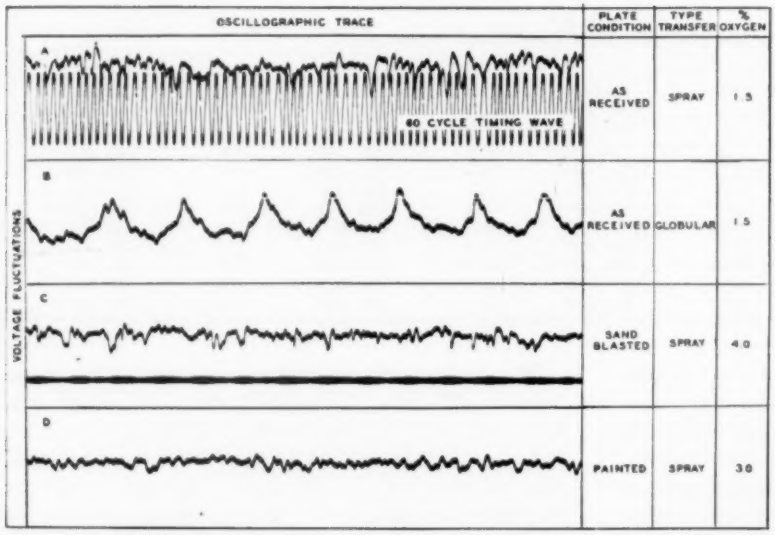
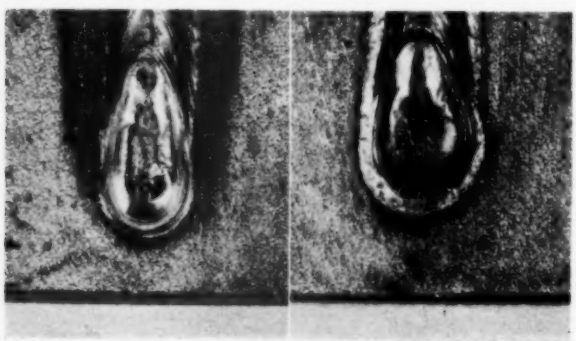


Fig. 17 Oscillographs of the arc voltage fluctuations encountered in welding semikilled low-carbon steel with various surface preparations

was placed on a movable carriage, traveled at a constant speed of 15 ipm under the welding arc. Figure 15 illustrates the setup of the welding apparatus used in conducting these tests.

An oscillographic trace made of the arc voltage fluctuations of the globular or drop-type metal transfer in the welding arc is shown in Fig. 17*B*. Definite and regular arc voltage fluctuations can be seen which are believed to coincide with the drops crossing the arc. This voltage variation ranged between 2 to 5 v. The voltage fluctuation obtained with the spray-type metal transfer in the welding arc on as-received steel is shown in the oscillographic trace *A* of Fig. 17. The voltage variation obtained with the spray-type transfer ranged from only 0.06 to 1.2 v which is indicative of the stable welding arc characteristics.

In order to obtain similar welding arc characteristics on the sandblasted steel specimens, it was necessary to increase the oxygen addition from 1.5 to 4%. An oscillographic trace of the arc voltage fluctuation using sandblasted plate and 4% oxygen is shown in Fig. 17*C*. Figure 18 illustrates the effect of oxygen additions to



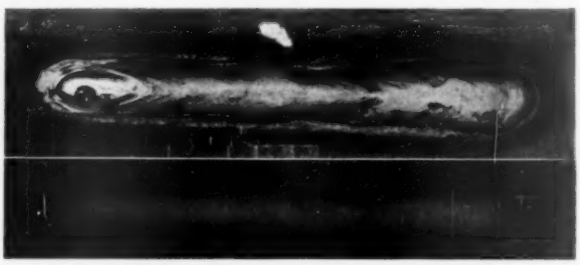
(*A*) (*B*)

(*A*) Oxygen, 3 to 4%, added to the inert-shielding gas eliminates surface melting around the bead. (*B*) Oxygen, 1% or less, added to the inert-shielding gas, resulting in surface melting around the bead.

Fig. 18 Effect of oxygen additions to the shielding gas toward elimination surface melting around the weld bead

the shielding gas using sandblasted steel plate. The important effect to note is that, with no or very little oxygen present in the shielding gas, an arc phenomena occurs, sometimes called cathodic action, which results in the surface melting around the weld-bead deposit. By increasing the oxygen content of the shielding gas, this cathodic action is neutralized, eliminating completely the surface melting around the weld bead.

The welding tests on steel, the surface of which had been painted with an iron oxide type sealer, resulted in very satisfactory weld bead soundness and appearance. The Class II filler metals (RHT and A6) were used for these welding tests. The current density and gas flow



(*A*) (*B*)

(*A*) Typical bead-weld appearance using Class II (Type RHT) filler wire. (*B*) X-ray of the bead weld shown in (*A*).

Fig. 19 Inert-gas-shielded metal-arc welding on semikilled steel coated with an iron oxide base paint sealer

was approximately the same as used in the preceding tests on sandblasted and as-received steel. However, the oxygen addition to the shielding gas was changed to 3%. Figure 19*A* illustrates the typical weld appearance obtained. An X-ray of the weld-bead specimen, shown in Fig. 19*B*, indicates that no porosity is present in the weld deposit. The arc voltage fluctuations that are shown in oscillographic trace *D* of Fig. 17 indicate that stable welding arc characteristics are obtained when welding over this particular type of protective coating.

FILLET WELDING

This portion of the investigation is concerned with the use of larger diameter steel filler wires for inert-arc welding of multiple-pass fillet joints. An earlier investigation which was performed using $^1/_{16}$-in. diam steel wire on fillet sizes ranging from $^3/_{16}$ to $^5/_8$ in. indicated that very little economic advantage could be realized by using the inert-arc process on fillets larger than $^3/_8$ in. (compared with the standard electric arc process). This was explained as a result of the larger diameter electrodes normally used in standard electric arc welding for the multiple-pass fillet welds as compared to the

constant size, 1/16-in. diam welding wire which is used with the inert-arc process.

The welding conditions which were applicable for the inert-arc welding of multiple-pass fillet welds using 3/32-in., type RHT, filler wire are as follows:

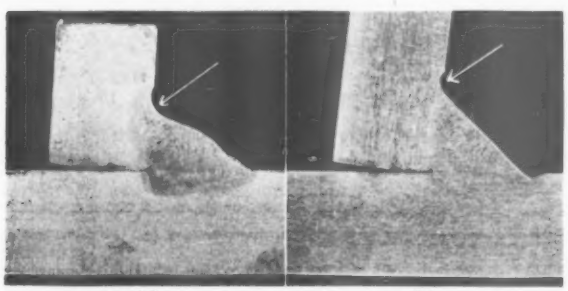
Welding current range, amp	400–500
Arc voltage range, v	35– 38
Deposition rate, lb/hr	10– 15
Argon gas flow, cfh	40– 50

Additions of oxygen were made to the argon-shielding gas ranging from 1 to 4% depending upon the position in which the joint was welded. Horizontal fillet welding requires the higher oxygen content as a result of the increased undercutting tendency of the 3/32-in. diam filler wire. In general, the operating characteristics of the 3/32-in. welding wire were not as satisfactory as those found for the 1/16-in. welding wire.

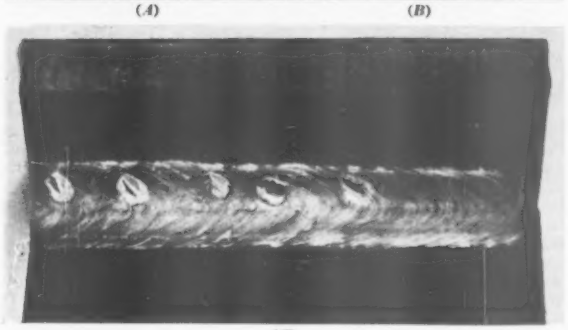
Comparative results of the welding tests using 3/32-in. filler wire for 3/8- and 1/2-in. fillet welds in both the flat and horizontal position showed a significant increase in the welding speed over that previously obtained using 1/16-in. filler wire. A comparison of the welding speeds obtained are as follows:

Position	*Fillet size, in.*	*Welding speed, ipm* 1/16 *in.*	3/32 *in.*
Horizontal	3/8	7	15
	1/2	3	5
Flat	3/8	8	16
	1/2	4	6

The effectiveness of using a larger diameter welding wire in a manual operation has not been developed to a point where the weld deposits are equivalent in quality to those obtained with the 1/16-in. filler wire.



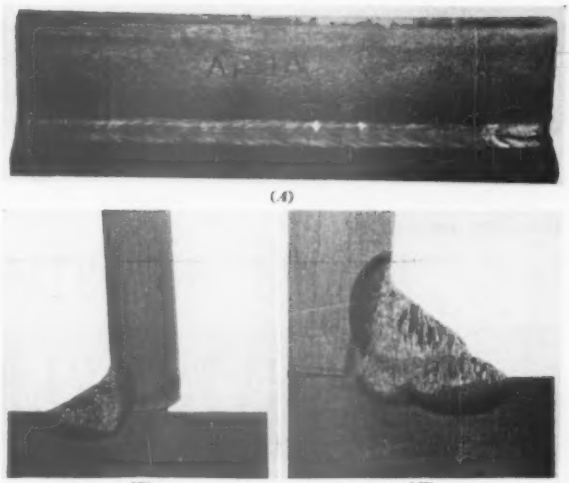
(*A*) (*B*)



(*C*)

(*A*) One-half inch horizontal-positioned fillet weld joint. (*B*) One-half inch flat-positioned fillet weld joint. (*C*) Outer appearance of the 1/2-in. flat-positioned fillet weld joint.

Fig. 20 Fillet weld (1/2 in.) illustrating the undercutting tendency encountered with 3/32-in., Class II (Type RHT) filler wire on semikilled steel



(*A*)

(*B*) (*C*)

(*A*) The single-pass, 3/8-in. fillet weld with Class II (Type A6) filler wire. (*B*) Illustrates the weld soundness in the 3/8-in. fillet weld joint. (*C*) Illustrates the pass sequence and soundness of the 1/2-in. multiple-pass fillet weld joint.

Fig. 21 Welding with 1/16-in. Class II filler wire on killed steel illustrates the lack of the undercutting tendency

One of the principal difficulties encountered with the inert-arc process is the strong tendency for undercutting. Figure 20 illustrates the undercutting obtained using a 3/32-in. filler wire on semikilled steel for preparing a 1/2-in. fillet weld in both the flat and horizontal positions. When using the 1/16-in. filler wire, the undercutting tendency is easier to control with proper manipulation of the electrode and relatively higher oxygen additions. Figure 21 shows the lack of undercutting which can be obtained using 1/16-in. filler wire.

There are several factors which affect the undercutting tendency as described above. Some of the factors are as follows:

1. The high current densities used create a strong arc force which results in a localized digging action in the base plate.
2. The relative lack of weld metal wetting action which is inherent to the argon-shielded inert-arc process.
3. The high cooling rates of the weld metal deposit.
4. The undercutting tendency is more serious on rimmed or semikilled steel than on killed steel.
5. Additions of oxygen to the shielding gas helps to overcome the undercutting.
6. Proper manipulation of the electrode.

CONCLUSIONS

This investigation of steel welding wires which are applicable to the inert-gas-shielded metal-arc process on semikilled, low-carbon steel has indicated the following conclusions:

1. Filler wires of the Class II composition are satisfactory for welding killed steel and fair for welding semikilled steel.
2. Filler wires of the Class IV composition are satisfactory for welding killed and semikilled steel.
3. Reverse polarity welding gives stable arc characteristic and consistent weld quality.

4. Straight polarity welding is satisfactory for welding light gage steel and for build-up applications.

5. The surface of the filler wires must be clean and properly protected from corrosion for satisfactory results.

6. Additional developments in filler wire compositions are necessary.

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Welding processes in relation to weldability; welding metal-

(*Continued on page 46*)

1953 Adams Lecture
Aspects of Welding Research in British Merchant Shipbuilding

The importance of adequate notch toughness at service temperature in mild steel is stressed and recent researches in welding aluminium alloys, residual stresses, full-scale structural tests on welded and riveted ships and structural components are covered

by R. B. Shepheard, C.B.E., B.Sc., M.I.N.A.

INTRODUCTION

I DEEPLY appreciate the high honor bestowed on me by your invitation to deliver the Adams Lecture. In the United Kingdom we follow the work of your SOCIETY with close interest; and recognize the American WELDING JOURNAL as a forum of international reputation for discussion of research findings and the application of welding science to Industry.

From kindred organizations in my country, I bring to you cordial greetings, and offer respectful good wishes to your eminent Founder and First President, Dr. Comfort A. Adams.

The use of welding in the building of all classes of merchant ships has steadily developed in Great Britain. The changeover from riveting has, however, been less abrupt than in the United States, due to compelling influences during the late war. Widespread and extensive modifications in shipyard layout and equipment have been effected in recent years. Figures 1 to 10 show representative examples of British welded construction for various types of merchant craft.

These developments afford ample proof of British confidence in the progress made possible by welded design in producing ships of improved performance and efficiency for commercial service.

The very rapidity of the welding revolution in world shipbuilding has inevitably brought problems in its train, some unforseen and distressing. Defects have been disclosed in certain welded ships, specially among those built during the war years. There have been tragic instances of hulls broken in two. Faults of less severity have included local fractures from hatch corners and at other discontinuities, these proving particularly troublesome at tanker bulkheads; and corrugations which have developed in the bottom plating of transversely framed dry cargo ships. In some cases, workmanship, welding and construction methods have proved unsatisfactory.

These deficiencies must be viewed in proper relation to the massive records of satisfactory service given by very large numbers of welded ships. They, nevertheless, present a challenge which has been vigorously met by extensive research and study ranging from the properties of materials to all features of general and detail design; and by constant vigilance throughout the building processes. As a result, the modern welded ship represents a great advance over her older sister, and has been released from the influence of riveted tradition.

These problems have permitted of no restricted national treatment; they are the concern of all Maritime nations. This is exemplified by the exchange and cooperation which has been maintained since 1943 in welding research undertaken on one side of the Atlantic by the United States Board of Investigation and its successor, the Ship Structure Committee, and on the other side by the Admiralty Ship Welding Committee. This collaboration has proved of very real benefit and has been enriched by many personal contacts and friendships.

The present Lecture attempts to outline some aspects of welding research affecting shipbuilding undertaken in Great Britain during recent years. The temptation has been resisted to include reference to other important spheres of research in which welded construction is incidental but not a basic factor in the investigations.

R. B. Shepheard is Director of the Shipbuilding Conference of London. Presented at the AWS Thirty-Fourth National Fall Meeting held in Cleveland, Ohio, week of Oct. 19–23, 1953.

BRITTLE FRACTURE IN MILD STEEL

The vital importance of adequate notch toughness at service temperatures in mild steel for welded shipbuilding was brought to light as a result of the thorough investigations undertaken in this country and also in Great Britain following failures in certain welded hulls built during the war years in the United States. No satisfactory explanation of all the features characteristic of these fractures was found "until the importance of notch brittleness in mild steel was realized. It was then evident that notch brittleness of some of the steel used in ships which had failed was a major factor in causing the trouble."[1]

Shipbuilders and Classification Societies were thus confronted with an unforeseen and most complex problem calling for urgent remedial action to ensure progressive development. They enlisted the collaboration of steelmakers and metallurgists, and research was intensified in many directions. As a result much progress has been made and amendments to material specifications introduced, which have proved their effectiveness in screening out unsatisfactory material in welded ships built since the war years.

Yet there remains much to learn and with the unremitting demands for heavier rolled material, especially for large tankers, it is imperative to continue research; and as a top priority.

The scope of the investigations in the United Kingdom can here only be reviewed very briefly. In 1945 Prof. J. F. Baker prepared for the Admiralty Ship Welding Committee a "Statement of the Problem" and, at the suggestion of the Committee, a conference was called at Cambridge by the British Iron and Steel Research Assn. in October of that year.[2] This was attended by a number of eminent experts; valuable ideas emerged and research interest was broadened. It was recognized that the phenomenon of brittle fracture, while by no means new, had assumed the greatest practical importance, with the advent of the welded ship.

Attention was first directed to the chemical composition of the material which had failed. These steels complied with established test requirements with which were associated control of sulfur, phosphorus and also, indirectly, of nitrogen, as recognized in normal good steelmaking practice. But the carbon content was high and the manganese unusually low. It was pointed out by Barr[3] that on the basis of impact tests over a range of temperatures, an increase in carbon tended to raise while an increase in manganese tended to lower the temperature of transition from ductile to brittle fracture. From this developed the recommendation that within the limits of composition determined by tensile requirements for mild steel, the ratio of manganese to carbon content should be of the order of about 3 to 1, this also ensuring better weldability. This recommendation translated into a specification requirement for plate material over $^1/_2$ in. in thickness effectively barred from further acceptance low-manganese steels such as were produced in America and in some Continental countries under wartime conditions. It was, nevertheless, realized that this additional control of analysis provided only a partial safeguard.

Emphasis then turned to the structure of the steel.

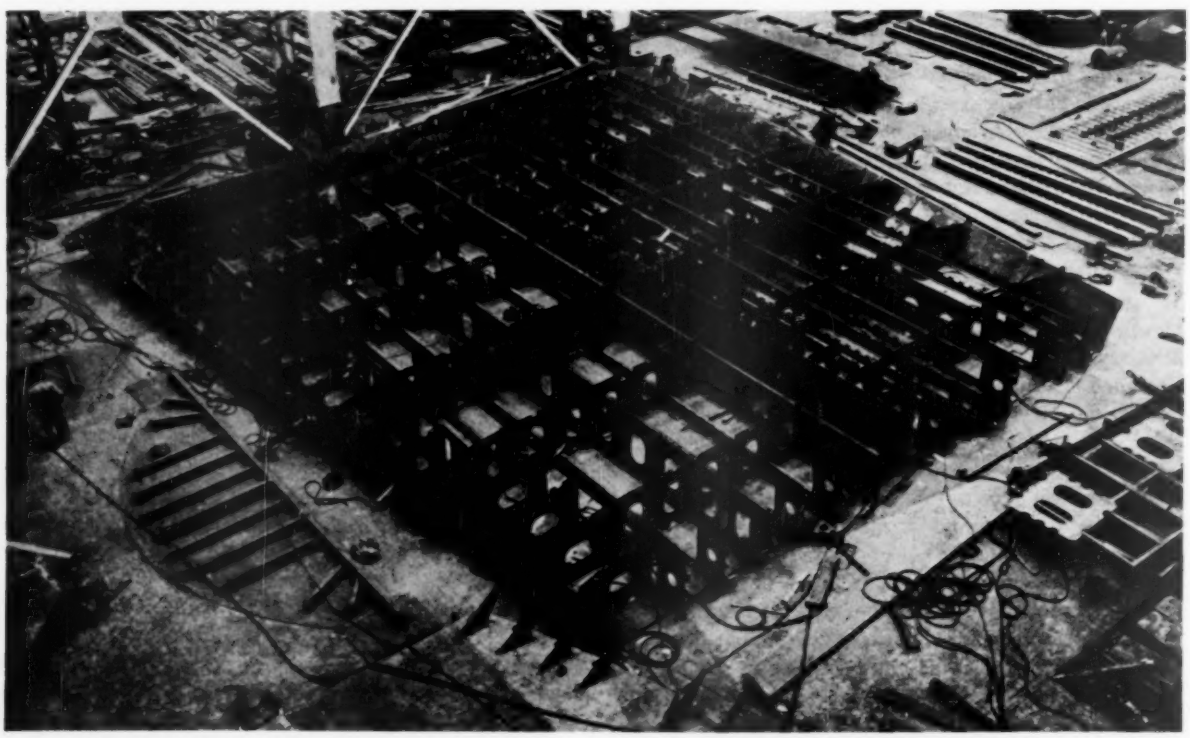


Fig. 1 All-welded longitudinally framed double-bottom structure of cargo liner; three units, combined weight 71 tons

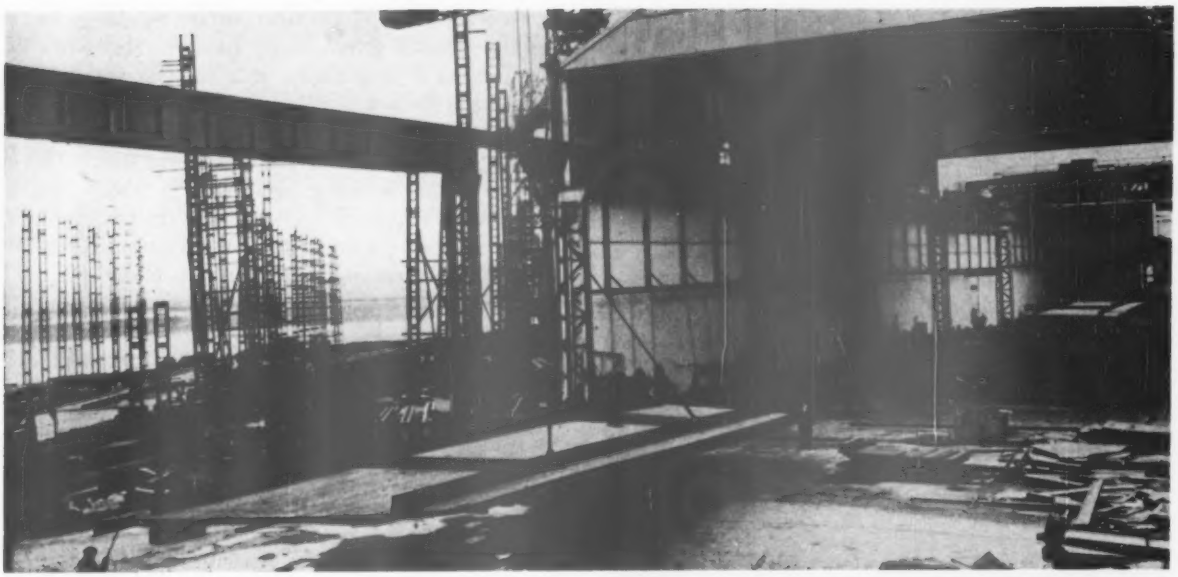


Fig. 2 Transfer of fabricated deck unit with wood sheathing laid, direct from welding shop to berth traveling crane

This is influenced by steelmaking practice in all its stages, including variations in composition, de-oxidization, mechanical treatment, temperatures of working, rates of cooling, directional effects, heat treatment after rolling and the thickness and volume of the finished product. BISRA set up an *ad hoc* committee to carry out a survey of the general level of notch ductility in British-made semikilled ship plates. Following a pilot survey, a wider investigation has been completed on plates from five manufacturers. Triplicate Charpy V-notch impact tests at 0° C were made on about 700 plates, and the general level of notch ductility for thicknesses ranging from $^1/_2$ to $1^1/_4$ in. from each works has been assessed by statistical analysis of the results. This has confirmed the known trend for notch ductility to decrease with increase in plate thickness. It has further disclosed differences between plates of equal thickness made by different manufacturers, the reasons for which are now being sought through a close examination of conditions of manufacture in each works.[4] A study is also being made by BISRA of the effects of welding practices and of the susceptibility of mild steels to strain ageing.

Results have recently been published of a further investigation[5] on plates rolled in two mills, the first object being to determine the effect of plate thickness and production variables on the Charpy V-notch transition temperature for semikilled steels, and the second to determine the general level of notch ductility of special qualities of mild steel. The general decrease of notch ductility with increasing thickness is attributed to higher rolling temperatures and slower rates of cooling. Some advantage is, therefore, to be expected from normalizing thicker plates. For the special quality steels the effects of killing with the addition of silicon or of aluminium, and normalizing, in addition to increasing the manganese/carbon ratio, have been compared and it would appear that to obtain a plate of high notch ductility at really low temperatures it is necessary to adopt a low-carbon high-manganese steel, normalized and killed with aluminium, although the latter greatly increases production costs (Fig. 11). It is clear also that special control of rolling and finishing temperatures has most beneficial effects, though this may give rise to practical difficulties.

The relation between laboratory tests and service failures has presented difficulties apparent from the early stages of investigation. Numerous forms of test pieces and methods of assessing notch ductility have been developed. Two types of test are being used in the United Kingdom to stimulate service conditions and for the purpose of obtaining fundamental information on the conditions of initiation and propagation of fracture. Both use a full plate thickness—an impracticability in standard impact testing. In 1945 Tipper developed a simple notch tensile test bar for

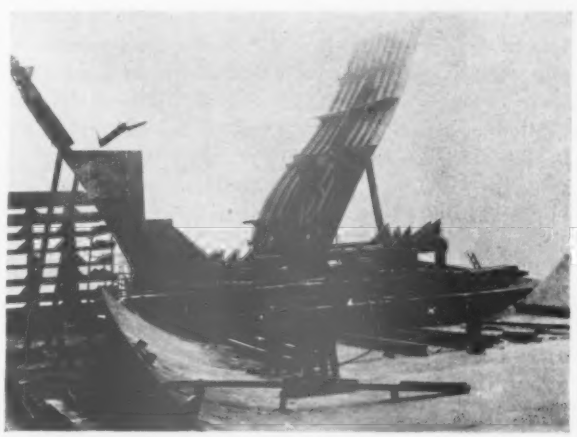


Fig. 3 Erection of double-bottom units and fabricated side shell panels of 32,000 tons deadweight tanker

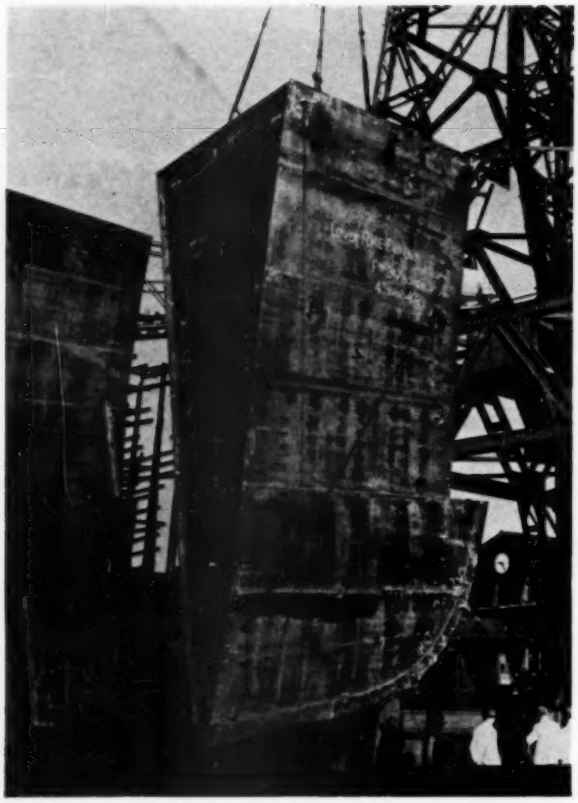


Fig. 4 50-ton welded bow unit for large passenger liner

determining transition temperatures and to relate fracture appearance to ductility as measured by reduction in thickness.[6] This test was the first developed in the United Kingdom which reproduced the characteristics of brittle fracture found in welded ships. The test has provided good correlation with service casualties, but it is desirable that the width of the test bar should not be less than two and a half times the thickness of the plate in order to obtain a sharp transition in the fracture appearance at a given temperature. Robertson has evolved a test in which a crack is initiated by impact; either a constant transverse stress is applied to a plate in which there is a temperature gradient or, alternatively, the material is maintained at a constant temperature.[7, 8] Correlation between impact, Tipper notch tensile and Robertson tests is fairly satisfactory in assessing the temperature at which the change in properties occurs. Numerical agreement is, however, impractical due to the different criteria adopted (Fig. 12).

The effect of dimensions in testing also renders comparison difficult between different forms of test. The magnitude of initiated discontinuities and of cracks in service must vary between wide limits, but the propagating fracture appears to have typical and constant form, when once established. In the small types of test specimen end effects form a large part of the fracture, thus masking its natural propagating form.[9]

Interpretation of fracture surface markings has recently received attention by Boyd.[10] He shows that the process of propagation of brittle fracture in a plate consists in the formation of a succession of disk-shaped cracks originating within the body of the material ahead of the main fracture front (Fig. 13). The envelope of the radiating fractures is parabolic, and the calculated orthogonal trajectories of the fracture fronts show good agreement with the inclination of chevron patterns measured upon natural fracture surfaces. The theory can also account for the chevrons having the same shape in plates of different thicknesses and leads to the conclusion that the work done in propagating a fracture is a material constant, a finding in agreement with Robertson's conclusions.

A method has been devised for measuring the energy absorbed in creating unit surface area of a crack, by recording the temperature wave release when the local plastic work is converted into heat as fracture proceeds.[11] This approach has indicated that for given materials and temperatures, the surface energy has stable minimum values.

The Admiralty Ship Welding Committee has given much attention to the choice of the most suitable test and criterion for assessing notch toughness. In the present state of knowledge the Committee considers that it is desirable to select a single standard test to be used for quality control, and for this purpose recommends general adoption of the Charpy V-notch impact test.[12] This proposal is in alignment with the practice of the National Bureau of Standards in their casualty investigations and has been endorsed by the International Institute of Welding. It has, however, been found that the methods by which the V-notch are machined can significantly affect the impact values, and closer specification of conditions for impact testing is therefore being considered. A great step forward would be achieved if an internationally accepted form of test were

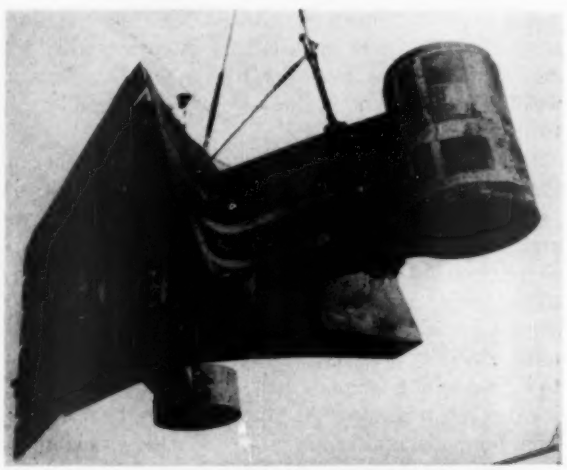


Fig. 5 Welded fabricated stern unit with shaft brackets carrying 42,000 s.h p. No castings or forgings. Weight, 46 tons

agreed. This should, however, in no way hamper the development or use of other types of test for special or research purposes and it is hoped that such investigations will throw much needed light on the mechanism of fracture in steel.

More fundamental researches are also in hand. These include work on pure iron and pure iron alloys which has been carried out by the National Physical Laboratory supported by BISRA.[13] This has shown that the lower the content of certain elements in iron the more significant do small amounts become, particularly in the presence of each other. Various studies are being made of fracture stresses in iron and other metal crystals.[14, 15]

The Rules of Lloyd's Register were amended in 1949 to require, for ship quality plate over $^1/_2$ in. in thickness, a manganese content not less than two and a half times the carbon content. This provision, similar in effect to the American Bureau Class B Specification, has involved little change in established practice since the War in the steelmaking world.

For main structural parts exceeding 1 in. in thickness in welded construction, the Society has further required that the properties and processes of manufacture of the steel used are to be specially approved for the purpose. This approach differs from that under the American Bureau Class C requirements, no detailed specification for the heavy material having been laid down. Steelmakers in any country are invited to submit for approval a type of steel which they can readily and consistently produce and which, in their opinion, has adequate notch toughness in thicknesses greater than 1 in. They are required to furnish full details of the proposed process of manufacture including de-oxidization and rolling practice, limits of composition and details of any heat treatment. In accordance with the proposed process, plates are rolled in several thicknesses from actual casts. From these plates, notch-bar impact tests are carried out over a range of controlled temperatures. From the data so furnished the Society is able to assess the suitability of the material relative to other accumulated data. If considered satisfactory, approval is given on the understanding that the steelmakers maintain substantially the same analysis and process of manufacture and will provide verification by periodical check impact tests. Routine notch testing from production is, however, not required by the surveyors. Steels so approved now number over forty from 11 different countries. They represent a wide variation in manufacturing practices from semikilled "run-of-the-mill" to elaborate and costly types based on full-killing, grain control and special heat treatment. The system permits initiative and encourages development suitable to individual manufacturing conditions without imposing a stereotyped specification, but approval is based on direct assessment of notch toughness determined by physical tests over a range of temperatures. It is nevertheless envisaged that with increasing knowledge and experience further safeguards and modifications in requirements may be developed.

There remain outstanding problems in this field still unsolved. Among these are the determination of

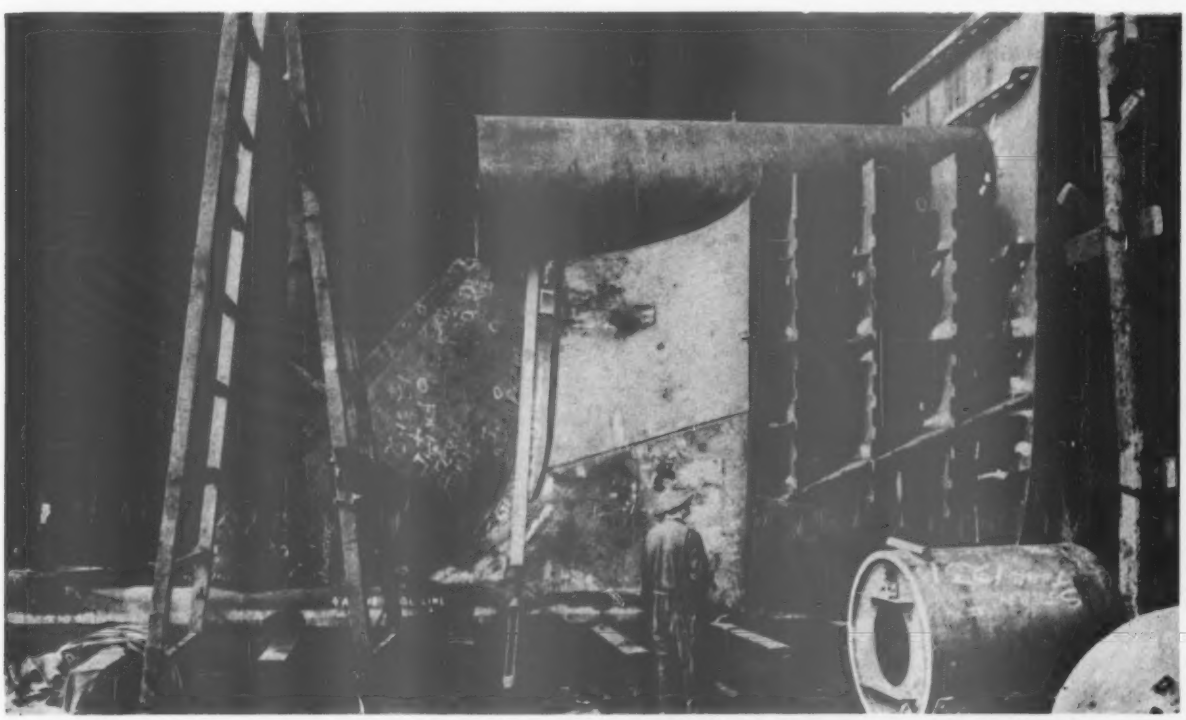


Fig. 6 Fabrication of stern structure for 26,000-ton deadweight tanker. Partly plated with temporary sterntube and contour plate in position; part of finished sterntube in foreground

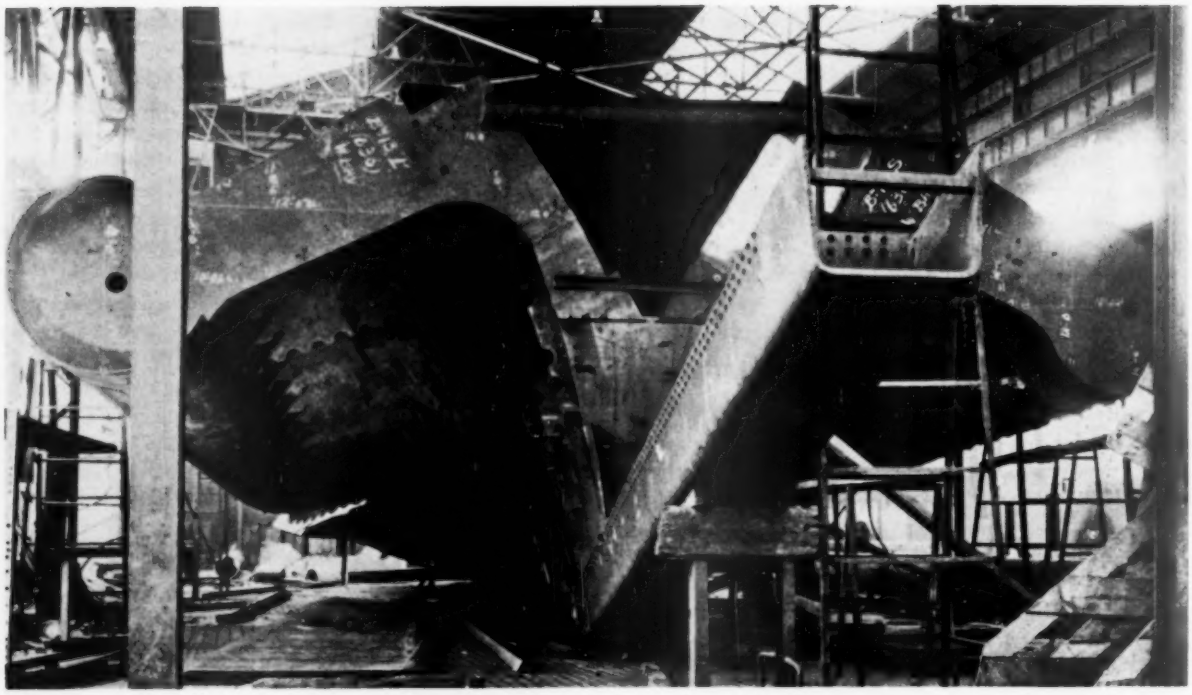


Fig. 7 Fabricated bossed framing for passenger liner

a suitable agreed criterion for the measurement of notch toughness, which must be correlated with service requirements for ships' structures; and a more thorough understanding of the metallurgical effects controlling notch toughness, particularly its reduction with increased thickness and for steels of acceptable weldability. Technical answers are needed to these problems in order to attain the objective that only materials are used which are of adequate and consistent quality for their duties—and at an appropriate cost.

RESIDUAL OR LOCKED-UP STRESSES

How do we now regard locked-up stresses, which for so long were widely held to be mysteriously responsible for welded ship failures? In 1948 a study was made at The Engineering Department, Cambridge,[16] of stresses in butt-welded mild steel plates, especially when welded under severe restraint. This showed that high locked-up stresses generally reaching the yield point occurred in the immediate vicinity of the weld, even where no reaction stresses, i.e., restraint, was present. It was demonstrated, moreover, that the magnitude and distribution of residual stresses could be greatly changed by small departures from established procedures, thus throwing doubt on the generally accepted belief that residual and reaction stresses could be controlled, provided correct welding procedures and sequences were followed. It emerged that cracking was due to lack of ductility in the weld metal on cooling and it was therefore necessary to follow well-established practices in order to limit the amount of plastic deformation required of the weld metal.

Other theoretical and experimental work led to the conclusion that residual stresses could have no influence

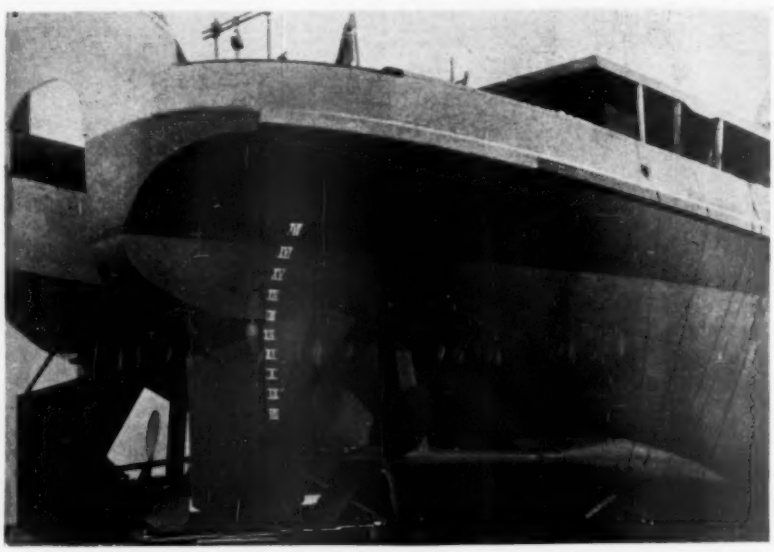


Fig. 8 Stern view of stern-well suctio n dredge

Fig. 9 Nonpropelled bucket dredge. Welded bucket ladder, weight 73 tons; and forward shears, weight 49 tons

on the static carrying capacity of a structure provided the material behaved in a plastic manner, and provided that residual stresses would not result in elastic instability. Under certain conditions the presence of residual stresses must be considered to reduce the load factor for elastic instability.[17]

It has also been shown that where no notch is present, high reaction stresses could not of themselves produce brittle fracture at temperatures below the transition temperature of the material. In more recent experiments,[18] however, spontaneous fracture has been produced in specimens in which a severe notch has been present associated with high locked-up stresses, the material having been cooled to below its transition temperature. Wells has offered an explanation for this type of failure.[19] He considers that provided a notch is present before the weld metal cools, work hardening can take place at the bottom of this notch to raise the the average residual stresses to the fracture strength of the material, thus initiating a brittle fracture which would then propagate at steadily diminishing average stresses depending on the crack length, under the influence of residual stresses alone, even if these were comparatively low.

It would seem, therefore, that residual stresses cannot be ignored in material which is notch brittle. Their potential danger can best be eliminated by ensuring a sufficient degree of notch toughness at service temperatures.

The Admiralty Ship Welding Committee has recently amplified its earlier findings on locked-up stresses in the following terms:[12]

(*a*) Regardless of the procedure, sequence of welding or restraint, every welding structure (unless stress relieved) contains locked-up stresses which locally reach the yield point of the material.

(*b*) Continued researches have so far not revealed evidence that these locked-up stresses have adverse effects on the strength or reliability or welded ship's structures, provided that the material, including the weld, is in a notch tough condition at the prevailing temperature.

(*c*) It is important, however, to appreciate that undue restraint during fabrication may lead to cracking during or shortly after welding and unless such cracks are found and dealt with they may lead to serious failures in service.

ALUMINIUM ALLOYS AND THEIR WELDING

Development of Weldable Alloys for Marine Use

Aluminium alloys are of great interest as structural

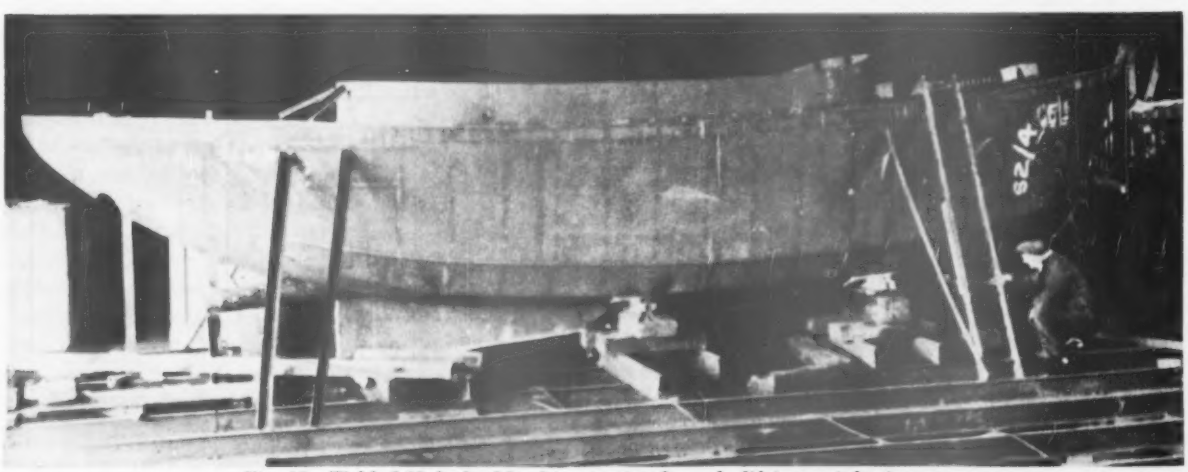


Fig. 10 Welded 28-ft double chine towing launch, lifting weight 4 tons

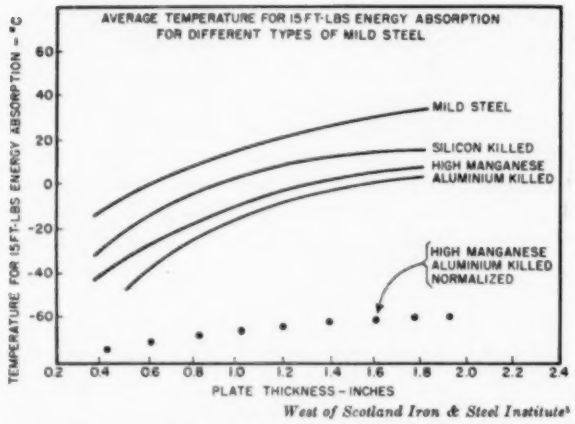


Fig. 11 Comparison of mean level of notch ductility for various qualities of mild-steel plate rolled in one mill

shipbuilding materials, alternative to mild steel, though their use has naturally been restricted due to high cost. Guidance in the choice of suitable alloys for marine purposes has been provided in the tentative requirements published by Lloyd's Register in 1947. These rules cover limits of composition for both nonheat-treatable and heat-treatable alloys of the aluminium/magnesium and aluminium/magnesium/silicon types, the minimum physical properties required being 0.1% proof stress—8 tons/sq in.; ultimate strength 17 tons/sq in., and elongation 10% on 8 in. Much research has been carried out in Great Britian to improve the weldability of these alloys. While welding difficulties due to the corrosion-resistant oxide film have been overcome by the inert gas processes, basic metallurgical factors are also involved, namely, gas reactions, cracking tendency, loss of alloying elements, loss of strength and reduction in corrosion resistance.

Gas porosity due to hydrogen picked up by the molten metal during welding occurs especially in the heat affected zone adjacent to the weld and is generally more troublesome in the aluminium/magnesium alloys than in other types. Investigations by the British Non-Ferrous Metals Research Association[20–22] have, however, suggested appropriate remedies. To eliminate hydrogen pores which may also occur due to moisture held in the surface oxide film, the metal should be thoroughly cleaned before welding and electrodes or welding wire stored in dry conditions.

The Aluminium Development Assn. has systematically studied the factors affecting cracking of welds under the inevitable conditions of restraint.[23] It has been found that in general a higher percentage of alloying elements in the filler metal plus additions of grain refining elements, particularly titanium and boron together, greatly reduce the risk of cracking. In arc welding aluminium/magnesium alloys the loss of magnesium may be offset by using filler metal containing a higher proportion of this element than the parent metal.

In the heat-affected zone the local increase in temperature results in significant reduction in strength of the heat-treatable alloys and to a lesser extent of the nonheat-treatable, when welded in the cold worked condition. The heat-affected zone may also exhibit some loss in corrosion resistance due to the redistribution of the constituents consequent upon heating to temperatures around the solidus. The metal may be susceptible to inter-crystalline corrosion which is, however, not normally observed in nonheat-treatable alloys containing less than about 4% magnesium.

There is now much experience in Great Britain in the production of aluminium/magnesium alloys; the most acceptable plate composition, taking into account all the above factors, appears to be a nominal 4¼% magnesium alloy. This has been standardized as NP. 5/6[24] and is now in wide commercial use. Latitude in range of composition permits manufacturers to select the most suitable for their production methods, and the desired mechanical properties may be obtained by varying the degree of cold working.

Alloy NP. 5/6 possesses a good combination of strength and ductility. It can be hot worked with reasonable ease, readily formed cold in the shipyard, and local reheating does not seriously affect its properties. Its welding characteristics are satisfactory and weld

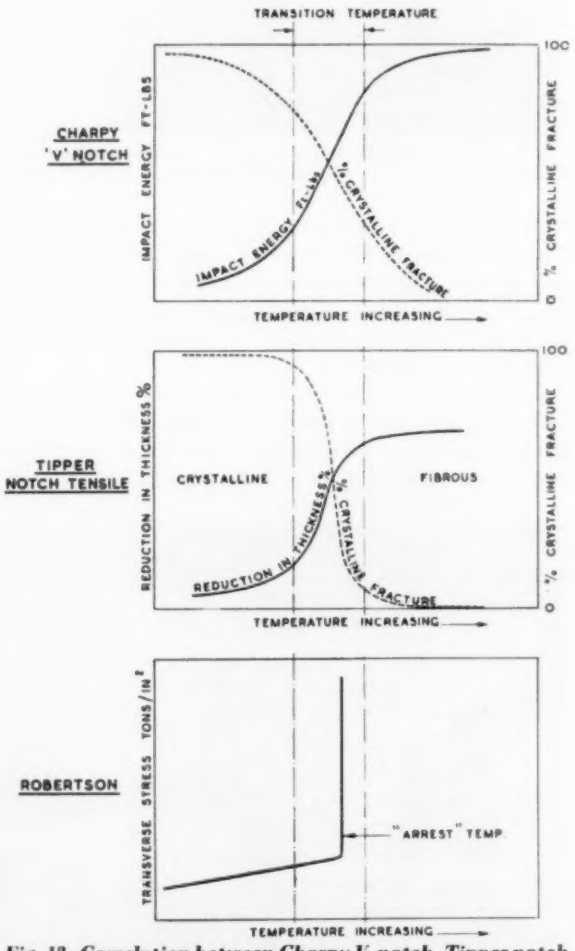


Fig. 12 Correlation between Charpy V-notch, Tipper notch tensile and Robertson tests in assessing transition temperature

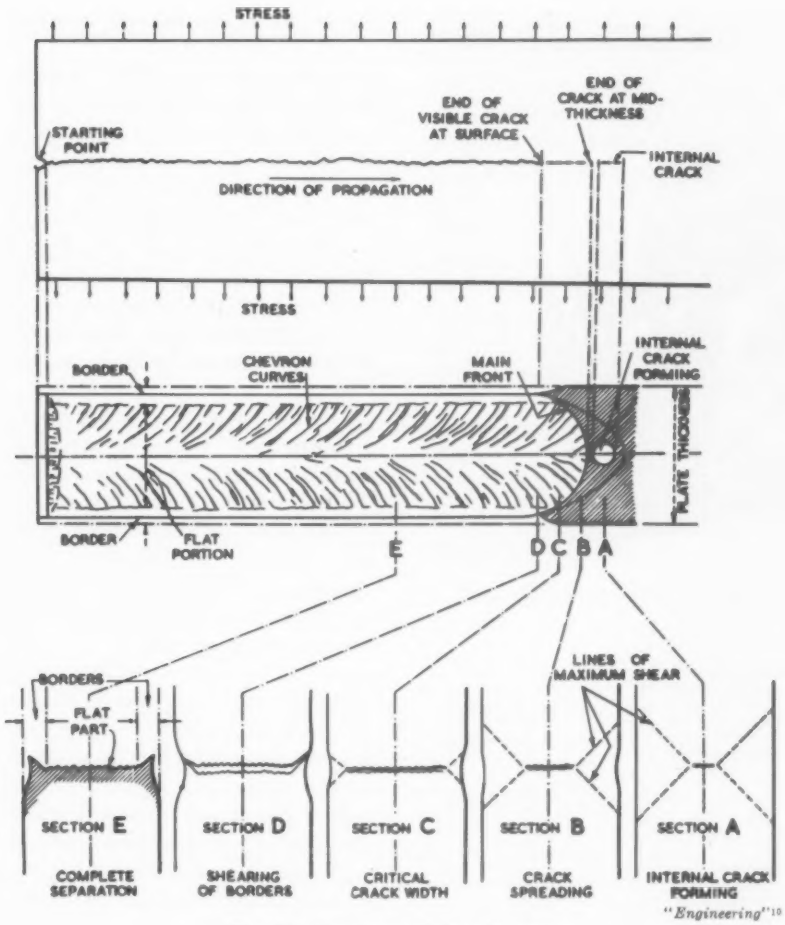


Fig. 13 Features of plate fractures

efficiencies exceeding 90% are commonly obtained. With filler metal of the same basic composition (or nominal 5% magnesium) resistance of the weld metal to corrosion is of the same order as that of the parent plate.

Work on Arc Characteristics

The British Welding Research Assn. have cooperated with the Electrical Research Assn. on work to study the electrical requirements for arc stability and the characteristics of welding circuits required for successful arc maintenance.

The experience of ERA on the fundamental physics of heavy-current high-voltage arc discharges has provided useful basic knowledge on the welding arc. This has been of particular value in leading to a full understanding of the electrical requirements of the Argonarc welding process, and has resulted in the development of a simple electronic device which enables the welding of aluminium by this process to be successfully achieved at an open-circuit voltage of 40 v, rms using any type of welding transformer, and without any other form of arc stabilizing device.[25] Under certain conditions, through the use of a series capacitator, this figure has been reduced to 30 v, rms. The device (Fig. 14) provides a damped unidirectional pulse of about 250 v peak lasting a few microseconds only, which is automatically timed to be injected at the beginning of each reverse polarity half-cycle. This ensures the reignition of the reverse polarity arc, and so, in practice, permits a reduction in the open-circuit voltage to a value of the order of twice the arc voltage. As the short duration surges injected are of comparatively low voltage, radio interference which always occurs with the commonly used spark injector is completely eliminated. If touch starting is impracticable then the low-voltage surges can be readily converted into timed high-voltage sparks to initiate the arc from cold, but once the arc has been started, the unit automatically reverts to the low-voltage surges for arc maintenance. This device is of comparatively recent development, but it is anticipated that considerable use will be made of the equipment, which is now in the commercial stage. This would reduce the size and cheapen the cost of welding transformers, make welding safer, improve the power factor and give better quality welding.

Work of a similar nature is also in hand on the characteristics of the inert-gas metal-arc process. Criteria have been formulated for both alternating and direct current which will ensure a considerably greater degree of arc self adjustment than is obtained in present practice. The criteria can be met either by suitable design of new welding plant or by the addition of auxiliary equipment to existing plant. A detailed account of this work will be published in the near future.

FULL-SCALE STRUCTURAL TESTS ON WELDED AND RIVETED SHIPS

The Admiralty Ship Welding Committee has undertaken a program of full-scale tests to throw light on the relative structural behavior of welded and riveted ships. This program developed in two stages; the first in still water, and the second under service conditions at sea. We were fortunate in Great Britain in having available certain classes of tankers and dry cargo ships practically identical in design, form and structural arrangements and of both welded and riveted construction. It is unlikely that such an opportunity will again occur.

In the first stage, two 12,000-ton deadweight tankers, the *Neverita* and *Newcombia*, the one welded and other almost entirely riveted, were submitted in still water to a range of loadings applied by changes in ballasting of

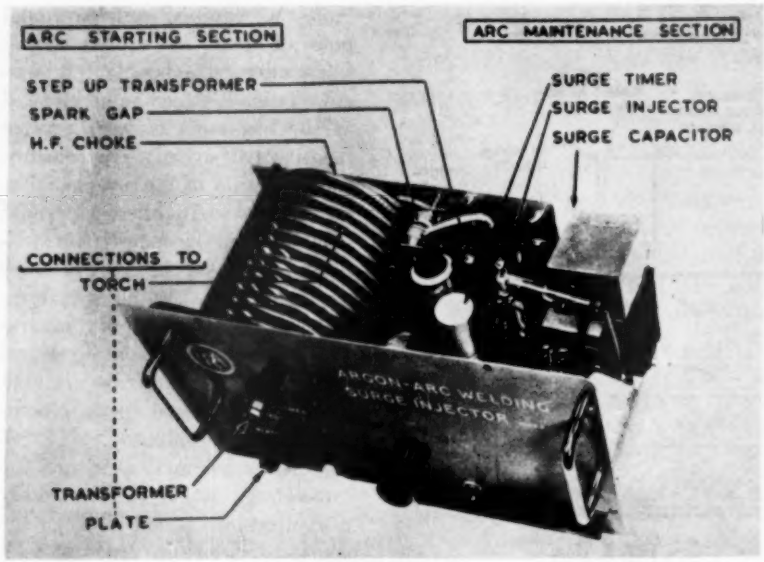
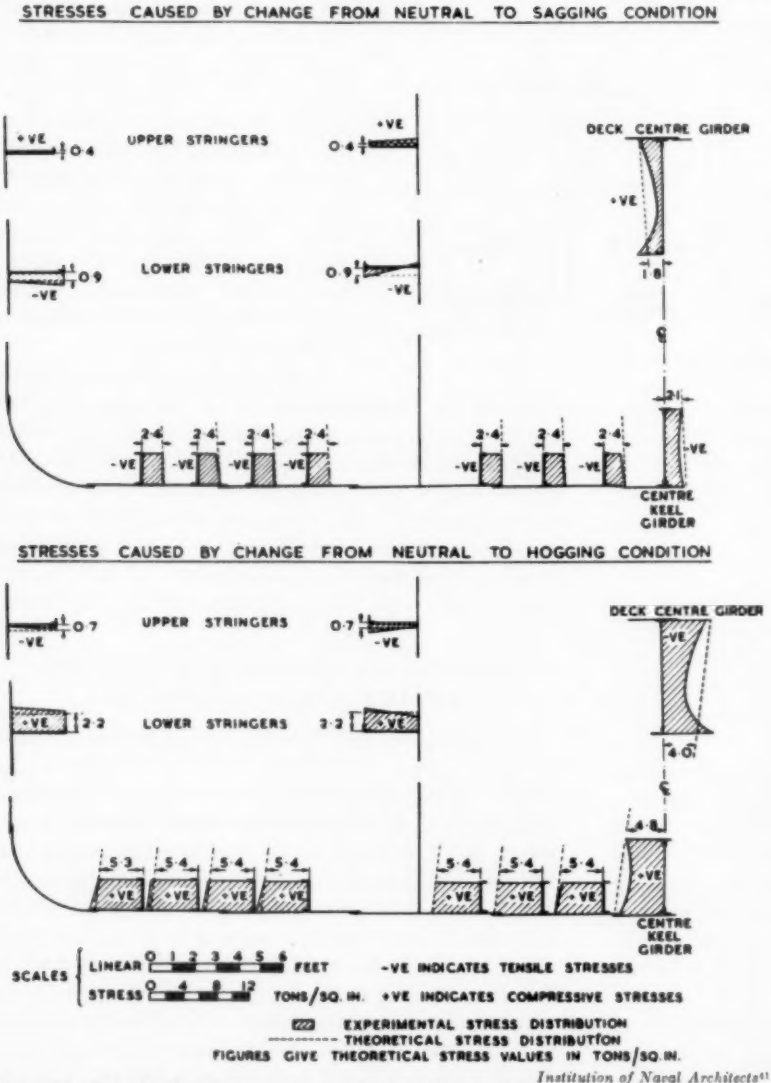


Fig. 14 Surge injector unit for argon arc welding at low voltage

different tank spaces.[26, 27] A large number of gages were fitted to measure bending strains in addition to direct strains, and hence to derive heart of plate stresses. The gages were arranged over a main section of the hull girder and also at selected positions to study local bending effects in plating panels and concentrations at discontinuities. Hull deflections were assessed by several methods.

The test showed, over the rather severe range of bending moments applied, no significant differences for the two ships in general stress distribution and deflection in the main hull girder; the results corresponding, within limits of experimental error, to those predicted from conventional beam theory. No evidence was found of rivet slip nor support for a commonly held belief that welded ships are stiffer. High local stresses were, however, observed at some positions due to local bending of plating panels and to concentrations at openings and other discontinuities.

The tests also showed that longitudinal framing members contribute effectively with their associated plating under stressing due to longitudinal bending moments (Fig. 15). This has provided valuable information in determining scantlings for longitudinal strength in tankers. It indicates that some variation is permissible between the relative areas of plating and longitudinals, which jointly provide the required sectional area of material in the bottom and top flanges of the hull girder. This variation, which is of great practical value in the choice of longitudinals must, however, be subject to limitations imposed by other considerations both in actual plate thickness and the scantlings of longitudinals. It is also important that adequate continuity and fixity be provided for the longitudinals in way of transverse bulkheads, and this is considerably easier of achievement in welded construction. Lloyd's Register Rules for Tankers, which were completely revised in June 1950, and formulated for direct application to welded design, incorporate tabula-



Institution of Naval Architects[1]

Fig. 15 Longitudinal stresses in longitudinal stiffening members, riveted tanker "Newcombia" (Similar distribution in welded tanker "Neverita")

tion of main scantling requirements on the above basis.

With the experience from the above and other static tests, and following a "pilot" sea-going voyage in the Tanker *Niso*,[28] the ASWC program was then extended to the second and more ambitious stage of measuring stresses at sea. It was recognized that simultaneous recording of strains and deflections in a complex ship's structure in the constantly changing conditions at sea presented immense difficulty and, furthermore, that such records without accurate knowledge of the corresponding applied forces would be of little scientific value. An indirect approach to the problem was, therefore, adopted. The sea trials were planned primarily to determine the forces acting on the hull, a few strain gages being fitted around the midship section for checking purposes only. Effort was concentrated on the provision of suitable equipment designed for synchronous recording, from which a complete evaluation of bending, twisting and shearing actions on the structure due to the sea at any moment could be deduced. Only one ship was required for these trials. Complementary to the measurements of forces at sea, the stress response of the two similar welded and riveted ships was to be determined in still water, when subjected to various conditions of loading. In the final stage the results from the still water trials would be applied to the loads derived from the sea trials, in order to estimate the probable maximum stresses at sea for both the welded and riveted ships—the ultimate object of the tests.

For these trials the ships selected were two 10,000-ton dry cargo ships, one the welded *Ocean Vulcan*, built in California, the other her riveted prototype the *Clan Alpine* built in Great Britain.

For the sea trials, the *Ocean Vulcan* was fitted with equipment specially designed to permit the determination of all forces acting on the hull at any instant. This included instruments for measuring direct wave pressure and instantaneous water line, accelerations, wind forces, angles of roll, pitch and yaw, ship's speed, engine speed and shaft torque, and also longitudinal stresses at a section near midships. Altogether some 700 wave profile indicators and 100 other instruments were installed, all arranged for remote synchronized reading at a central recording panel by photographic exposures twice per second (Fig. 16).

The equipment was operated by a small experimental crew during eight round voyages in normal North Atlantic trading over a period of 17 months, some 200 days being on the open ocean. The weather experienced was of varying severity and full gales were encountered.

The complementary still water tests were made on the *Ocean Vulcan* and *Clan Alpine* in the River Fal under a large range of conditions. Loading was applied mainly by water ballast and for this purpose main bulkheads were reinforced to permit the holds and in some cases the 'tween decks to be filled, a special pumping system also being installed. The ranges of hogging and sagging moments and conditions imposing severe trim, torsion and heel called for most careful control during the whole

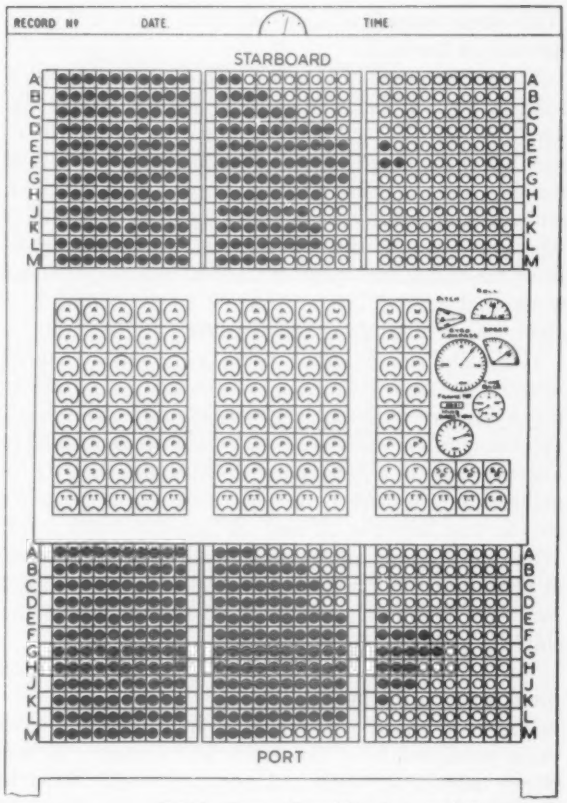


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Fig. 16 "Ocean Vulcan" sea trials—recording panel

A = Accelerometers. P, S. C. P. = Pressure gages. S, T. T. = Strain gages. W = Wind gages. T = Torque. E. R. = Engine speed A–M = Wave profile indicators.

period of tests to ensure the ship's safety. Comprehensive readings were made of direct and bending strains at main sections of the hull, at local discontinuities and openings, and in certain plating panels, together with records of the hull deflections.

The experimental work under this program was completed early in 1948. Analysis of the immense volume of records has presented a lengthy and formidable task, which has been brought to completion under the supervision of F. B. Bull who, as leader of the experimental party, had been associated with the tests since their inception. A series of Reports has been completed[29–33] and early publication is expected.

The detailed Report[31] on the *Ocean Vulcan* Sea Trials, which has recently been published, includes a review of previous work on ocean waves and strain measurement at sea. The basic assumptions underlying the trials are discussed, the instrumentation described in detail, and also the methods adopted in reducing and presenting the results.

The main conclusions from these sea trials may be summarized as follows:

The greatest recorded range of vertical longitudinal bending moments was 190,000 tons-ft corresponding to a stress range of 8 tons per sq in. at the top of the sheerstrake amidships. From theoretical considerations the sagging moment constituted about 55% of the total.

(This stress range is of course additive to the still water stresses on the hull.)

The above range of bending moment was associated with waves 35 ft high and between 600 and 700 ft long. The greatest range of bending moment amidships occurs when the length of wave approximates to that of the ship, and according to oceanographic data the maximum height ever likely to occur for a wave of 416 ft (the ship's length) is about 35 ft. Under such conditions the maximum range of vertical bending moment would not exceed 260,000 tons-ft corresponding to a stress range at the sheerstrake of 11.0 tons per sq in.

Horizontal longitudinal bending moments caused stresses, in some conditions, of similar magnitude to those due to concurrent vertical bending. The maximum range observed was 80,000 tons-ft corresponding to a stress range of $2^1/_2$ tons per sq in. at the sheerstrake amidships, and such ranges occurred when the ship's course was between 20 and 50° to the wave front. When longitudinal and vertical bending moments were in phase the stress range on one sheerstrake (or bilge) was very different from that on the other side of the ship[34] (Fig. 17).

Torsion moments were small and had little effect on the stresses in the hull girder.

Water pressures were closely in agreement with those predicted from the trochoidal theory. It was shown that for this ship in a seaway dynamic terms in the determination of vertical longitudinal bending moments amidships tend to cancel each other. In consequence a reliable estimate of these bending moments for any particular wave length and height in head or following seas can be made from the assumption that the ship is in static equilibrium on the wave, provided the Smith correction is applied.

The relation of these conclusions to the detailed analysis from the still water tests of stress response in the welded and riveted sister ships is likely to throw strong emphasis on the effects of local stress concentrations.

It is hoped that this work, when finally available for critical study, will be found to have contributed usefully to our knowledge of the "way of a ship in the midst of the sea." While the ASWC is undertaking no further ship structural investigations, these figure prominently in the research program of the British Shipbuilding Research Assn.

Vibration

Opportunity was taken during the structural trials on the *Ocean Vulcan* and *Clan Alpine* to carry out vibration tests on these two ships as part of the BSRA program to develop new and to improve existing methods of calculating critical frequencies of ships' hulls and to obtain information on the effects of loading, depths of water and other conditions.[35]

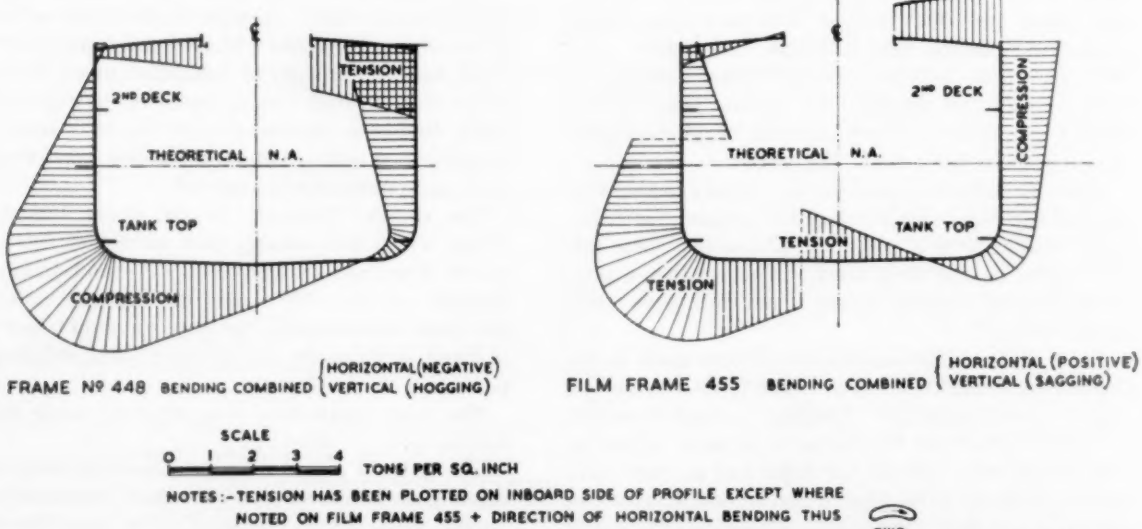
Vibrations were excited by a machine specially designed by Lloyd's Register mounted on the poop of each ship in turn. Records were obtained of critical frequencies and vibration profiles in various modes of vibration under widely different conditions of load distribution and displacement, and also in the case of the *Ocean Vulcan*, in normal loaded service condition.

Among other results the tests showed that the critical frequencies in the two forms of construction were closely in agreement, when free from the influence of restricted depth of water. The welded ship, however, tended to have larger vibration amplitudes suggesting that structural damping is greater in the riveted ship.

TEST ON STRUCTURAL COMPONENTS

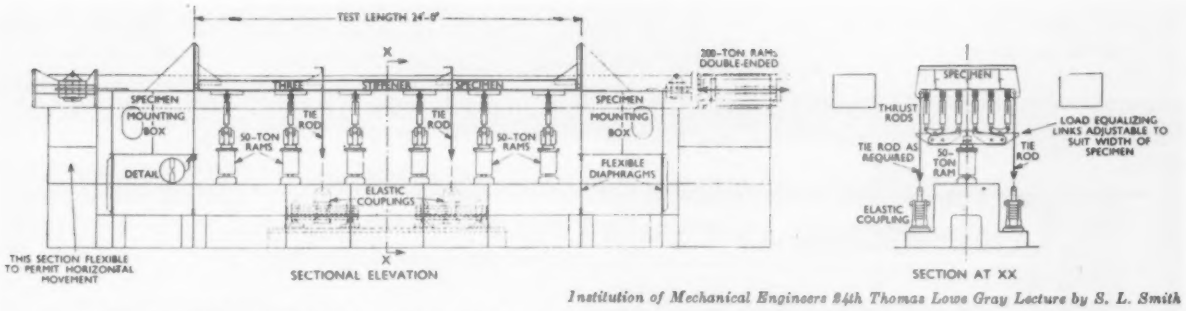
Glengarnock Experiments

Systematic full-scale testing of ships' structural mem-


TENSION
2ND DECK
THEORETICAL N.A.
TANK TOP
COMPRESSION
FILM FRAME Nº 448 BENDING COMBINED { HORIZONTAL (NEGATIVE) VERTICAL (HOGGING)
2ND DECK
COMPRESSION
THEORETICAL N.A.
TANK TOP
TENSION
TENSION
FILM FRAME 455 BENDING COMBINED { HORIZONTAL (POSITIVE) VERTICAL (SAGGING)
SCALE
0 1 2 3 4 TONS PER SQ. INCH
NOTES:-TENSION HAS BEEN PLOTTED ON INBOARD SIDE OF PROFILE EXCEPT WHERE NOTED ON FILM FRAME 455 + DIRECTION OF HORIZONTAL BENDING THUS
FWD

Institution of Naval Architects[34]

Fig. 17 'Ocean Vulcan" Sea Trials—Examples of longitudinal stress distribution under combined horizontal and vertical bending moments (derived from strain gages)



Institution of Mechanical Engineers 24th Thomas Lowe Gray Lecture by S. L. Smith

Fig. 18 BSRA machine for testing ships' structural members under both lateral and axial loading

bers has been carried out since 1938 on a specially designed machine installed at Messrs. Colvilles Glengarnock Works. This work, originally undertaken by the Institute of Welding staffed by the British Corp., under J. L. Adam, has been directed by BSRA since 1945, the experimental team now being provided by Lloyd's Register.

Comparative tests have been made on many varieties of single-span mild-steel specimens, 16 ft in length, both riveted and welded, consisting of one or three stiffeners connected to plate panels 24 or 72 in. in width, and subjected to lateral load, either uniformly distributed or simulating a pressure gradient. Stiffeners have ranged between 6 and 12 in. in depth, and include many different forms of rolled sections, and also flanged plates. The tests have explored the effects of various types and sizes of stiffener end connections and of the rigidity in attachment to the base structure. Aluminium alloy specimens with different forms of extruded sections have also been tested.

Five detailed reports of these investigations have been published.[38–40]

Results have clearly shown the advantages to be derived from the improved fixity of welded compared with riveted construction. This fixity significantly reduces both stress and deflection in welded stiffening members. At bulkheads, for example, in which the whole structure, including stiffeners, end brackets and boundaries are welded, it has been found that the strength modulus may, in general, be reduced by 15% and even larger reductions in stiffness permitted.

In deciding suitable reductions from riveted standards, it is, however, most important to assess the effectiveness of "backing up" behind the stiffener ends.

Through analysis of the test data, working codes of practice have been formulated for deriving appropriate scantlings under a wide variation of particular conditions, e.g., span/depth ratio and type of end stiffener connections. With this experimental background, much saving in structural weight has been achieved and with proved efficiency in service.

The real improvements in design made possible through these investigations have necessarily been confined to structural components with single span stiffening and under lateral loads only. A second machine has therefore been developed by BSRA for the testing of larger specimens subjected to axial as well as to lateral loads, and for the study of continuous beams having one or two elastic supports in their length.

The design of this second machine is shown in Fig. 18.

Lateral loads are applied through six 50-ton hydraulic rams adjustable for uniform or graded pressure over the test length of the specimen, and distributed uniformly across its width by levers or push rods. Axial loading is applied by three 200-ton double-ended rams sufficient to develop an average stress in the size of units contemplated of the order of 8 to 10 tons per sq in. tension or compression. Arrangements are incorporated for intermediate elastic supports to the specimen, dividing its span into two or three equal or unequal parts. Tie rods connect across girders on the test specimen to elastic couplings on the base plate of the machine. These couplings consist of high-tensile light-alloy leaf springs whose stiffness can be widely varied. This material has been chosen in preference to steel to take advantage of its low Young's modulus and consequent saving in bulk and weight.

This second machine is now in operation. Its versatility will permit methodical testing of specimens including vertically stiffened or corrugated bulkhead panels fitted with horizontal girders, stiffened panels of shell and deck plating, and pillars subjected to side loads.

Double-Bottom Compression Tests

Many welded dry cargo ships have developed corrugations in the bottom plating between floors, an unforeseen defect which has necessitated awkward and costly repairs.

The bottom plating of these ships is slightly distorted during construction at the line of the transverse floors, due to thermal contraction at the connecting fillet welds. These deflections, though small, have evidently provided sufficient initial eccentricity to permit progressive unfairness and corrugation in the plating panels in service under repeated compressive loading combined with hydrostatic pressure.

This apparent sensitivity to what might have been considered a tolerable degree of unfairness in the plating is evidence of the increased compressive stresses to which the bottom structure of the modern cargo ship is subjected.

For better understanding of this defect, a series of

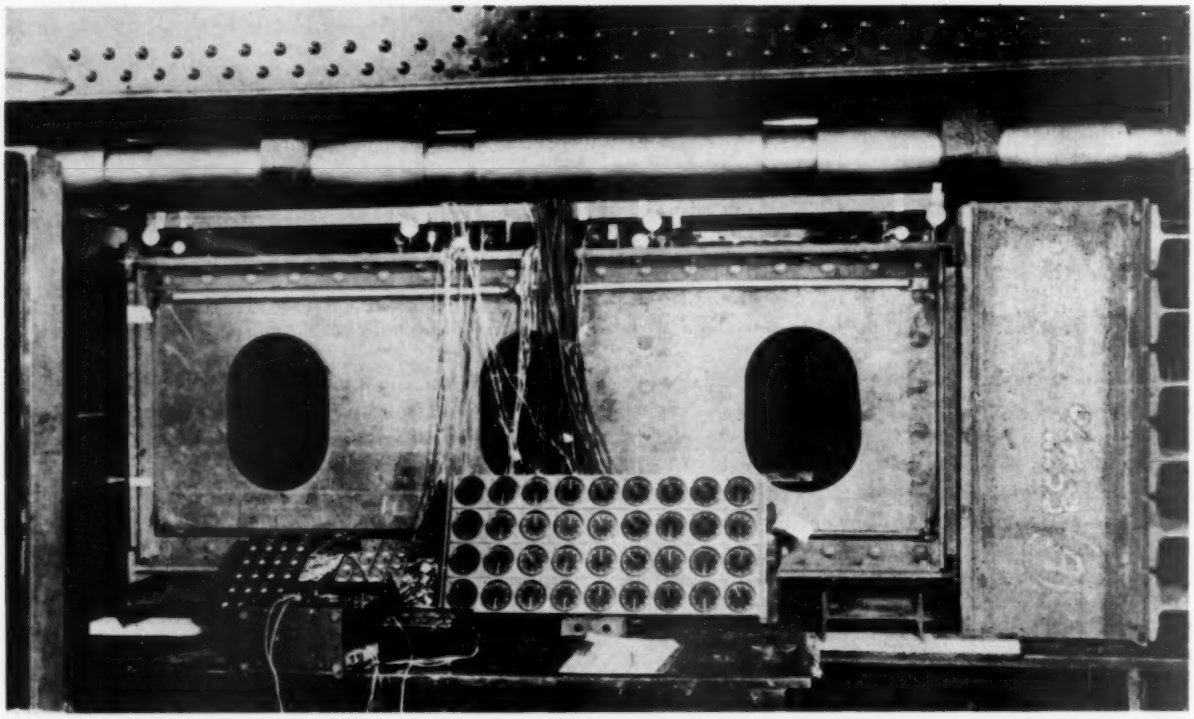


Fig. 19 Double-bottom compression tests—riveted specimen mounted in testing machine, showing dial and electric resistance strain gages on top plate

tests has been undertaken to observe the difference in behavior under compression of similar panels of plating in riveted and welded specimens representing full-scale sections of ship's double bottom, and the effects of fitting fore and aft stiffening to the welded panels. This program has been carried out by Lloyd's Register on behalf of BSRA.

Five specimens have so far been tested, each 10 ft wide by 7 ft 6 in. in length and 3 ft deep, constructed with four solid floors and bounded by two continuous longitudinal girders. For symmetry under test the top and bottom plates in each specimen have been made of the same thickness. Two specimens were riveted and two welded, each pair being of the same scantlings. Workmanship was to good shipyard practice. One welded specimen was subsequently reinforced at the test centerline by intercostal fore and aft stiffeners welded to the top and bottom plating and to the floors. The program is being continued with other thicknesses of plating and alternative forms of panel stiffening.

Testing was carried out on a 1250-ton machine at Dorman Long's Middlesbrough Works as indicated in Fig. 19. This shows the method of mounting the specimen to apply compressive loads in the plane of the top and bottom panels and at right angles to the floors. Instrumentation was arranged to determine, under different loads, the surface contour of the top plate (the bottom plate being inaccessible for observation), heart of plate and bending stresses in the several panels of top plating, and horizontal strains and distortions of the panels between floors and between load-bearing faces.

From these tests, the following general conclusions may be drawn:

The deflection in plating panels between floors before loading in each case was larger in the welded than in the riveted specimen.

The degree and pattern of initial deflection in the welded panels exerted major influence on their behavior and load-carrying capacity—the greater the initial deflection, the earlier the collapse of the panel. Failure of the welded specimens commenced when strain on the plate surface reached the yield point, but redistribution of the stress due to plastic flow in the panels enabled these to withstand a still greater load. Welding of the floors provided angular restraint at the plating boundaries with consequently only a gradual increase in panel deflections. On the other hand, fixity at the floor connections to the riveted panels was slight or absent, and the panels buckled suddenly. The efficiency of the plating panels, i.e., the ratio of the actual load carried by the deflected panel to that which would be carried by the same panel with a uniform stress equal to that at the longitudinal edges, remained high in the riveted panels under edge forces of the order likely to be experienced by a ship at sea. For welded panels, however, the efficiency dropped under load, but due to restraint at the floors did not decline thereafter within the limits of the stresses imposed.

Permanent set was observed in the welded specimens at a lower load than in the riveted.

The fitting of an intercostal stiffener forming a panel breaker at the test centerline of a welded panel having

substantial initial deflection (thus reducing the proportions of the panel boundaries from 4:1 to 2:1) restored the load-carrying capacity of the panel, so that it was at least equal to that of an unstiffened panel with slight initial deflection.

Other investigations now in hand indicate that where transverse forces, corresponding to hydrostatic pressure, are applied to a series of plated panels subject to alternating loads in their plane, a build-up of plastic deformation can take place in a panel under what are normally straight elastic conditions.

Service experienced and experimental data have resulted in the requirement by Lloyd's Register of increased bottom plating thickness and fore and aft double bottom stiffening in transversely framed welded dry cargo ships.

Naval Construction Research Establishment Testing Frame

Facilities for testing full-scale structures in Great Britain have recently been greatly extended by the completion of a special frame at the Naval Construction Research Establishment, Rosyth.

This is in the form of a large box with internal dimensions 69 ft in length by 33 ft wide by 39 ft high, a hinged door being fitted at one end for insertion of the test specimen (Fig. 20).

The walls are of strong cellular construction designed so that the test specimen can be loaded as required by a series of 500-ton hydraulic rams which can be arranged at angles up to 45 deg. At each end forces of 2000 tons can also be applied horizontally.

This test rig is primarily intended to study the design of warship structures but will also be available, provided defense requirements permit, for investigating merchant shipbuilding and other problems.

FATIGUE TESTING

In contrast to aircraft, there is little evidence that fatigue strength represents a basic criterion in the design of ship's structures. There are, in fact, conflicting views on the form of test most suitable to reproduce the fluctuating loads to which hull components are subjected.

The resonance vibration method, which is also being adopted by the British Welding Research Assn. for testing other full-scale structures, has been applied in a series of fatigue tests on welded specimens consisting of a steel plate 10 ft long and 2 ft wide stiffened by two toe-on angle sections[41] (Fig. 21). Various welding and constructional details representative of shipbuilding practice were incorporated. A main feature of the work was to determine the effectiveness of different forms of reinforcement to butt welds in the angle stiffeners. It was found that under fatigue conditions these reinforcements tended to reduce the strength due to the discontinuities introduced, and that the most ef-

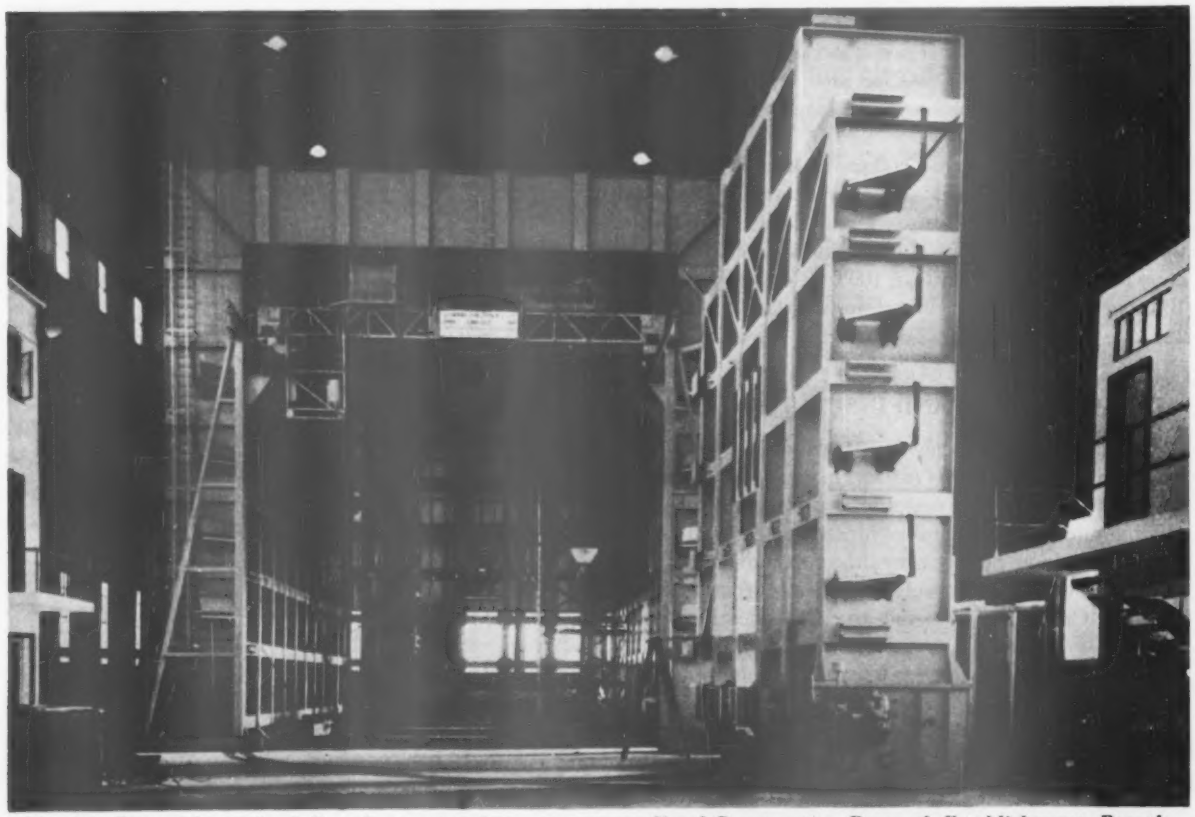


Fig. 20 Testing frame for full-scale structural components, at Naval Construction Research Establishment, Rosyth

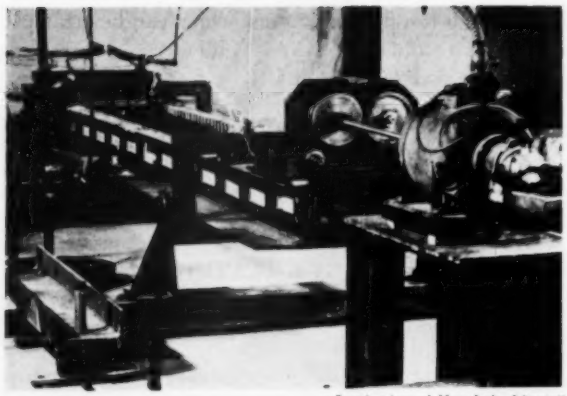


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Fig. 21 Fatigue tests on plate specimen with two toe welded angle stiffeners. Exciter in foreground; specimen supported near nodal points

fective connection was formed by direct butt welds of high quality.

Fatigue tests are particularly searching in assessing the effects of faults in welded joints; and their possibilities are being explored in relation to acceptable radiographic quality. Exploratory tests undertaken by the Naval Construction Research Establishment on defective butt welds[42] have led to the development of a progressive program by BWRA. In the first instance, butt welds in $^1/_2$ and $1^1/_4$ in. thickness mild steel will be tested. Control tests are to be carried out on the plain plate material and the butt-welded specimens will be prepared, both by manual and automatic arc welding with square butt, V-, X-, and U-edge preparations. Before investigating defective butt welds, the fatigue strength for 2 million cycles for each type of weld will be determined from specimens showing the highest possible radiographic quality.

This work will be undertaken in the large Losenhausen machine installed in the BWRA Fatigue Laboratory at Abington. This machine is designed for an alternating load range of 100 tons, which may be applied anywhere within the limits of 100 tons compression and 100 tons tension, on specimens up to 6 ft in length (Fig. 22).

WELDING AND INSPECTION

Methodical and informed supervision is essential to maintain good standards of workmanship in all stages from the preparation of material, in the actual process of welding and in the control of procedures and sequence. Shipbuilders now possess a wealth of experience supplementing the guidance circulated by the Admiralty Ship Welding Committee[43, 44] and the Classification Societies.

In Great Britain with our uncertain climate, control is greatly simplified when the work is carried out under cover. Automatic welding by submerged arc processes is rarely used on open berths. These have been important factors in the development of prefabrication in large units and panels, for which extensive changes in shipyard lay-out and lifting equipment have been made.

In welding long joints at the berth, such as those connecting large units, special precautions must be taken particularly in thick shell and deck plating. To avoid risk of cracking, the heat gradient between the hot weld deposit and the mass of cold parent material should be reduced as far as possible. This is best ensured by the use of large deposits, and prewarming in cold weather is essential. There are still many advantages in fitting some longitudinal riveted joints in the larger welded ships.

Low hydrogen or basic coated electrodes, now marketed by most British manufacturers, possess valuable qualities particularly in their resistance to cracking and high impact values at low temperatures. Their welding characteristics differ from those of other coated electrodes generally used for mild steel, and with these welders need to become familiar. Special precautions are necessary to keep the welding rods dry and in some types there is a tendency to fuming. The merits of these electrodes are well recognized by shipbuilders and their use is being extended, especially for restrained conditions of welding.

Among the various methods for nondestructive testing,[45] radiography has proved a most valuable shipyard technique for the control of welders, in the checking of procedures and the examination of critically placed or restrained joints. A marked trend in the United Kingdom is toward the use of radioactive isotopes in place of X-ray apparatus. This has received great impetus

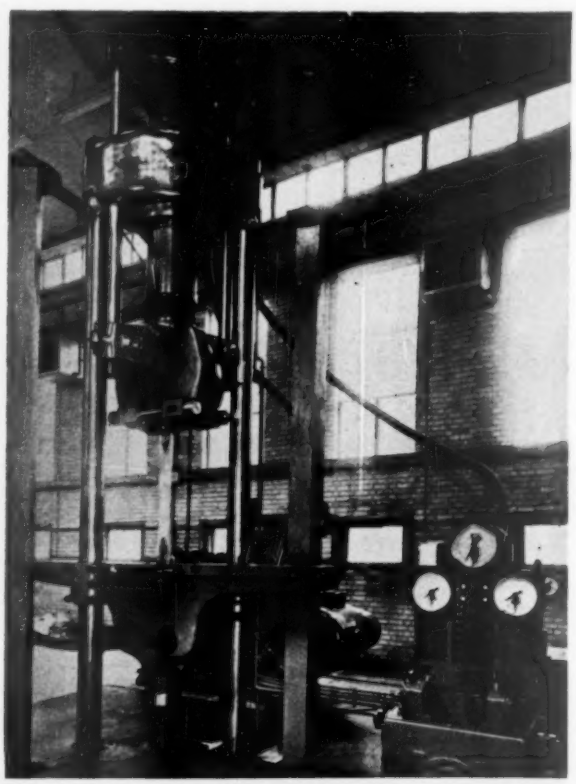

Fig. 22 100-ton Losenhausen fatigue testing machine at BWRA Fatigue Laboratory, Abington

through the production of these isotopes for industrial purposes at the Atomic Energy Research Establishment, Harwell. While isotopes of tantalum or cobalt are suitable for heavy work such as castings and forgings, iridium 192 which gives less intensity of radiation, has characteristics best suited for examining welds in ship's plating. This isotope is cheap, has a half life of about 70 days, and gives a good level of contrast, though the exposure time is naturally much longer than with X-ray. Precautions to protect personnel against exposure are thorough, but not restrictive.

STRUCTURAL DESIGN

For successful detail design of all parts of welded hulls, sharp discontinuities or notch effects in the contour or disposition of the material must be avoided to all practical limits. This is, of course, an established principle but it is evident from experience that some local discontinuities which may lead to trouble have not yet always been sufficiently recognized. The eye of the designer and draftsman must be specially trained to detect and to "smooth out" possible localities of concentration at which acceptable "average" design stresses may be greatly exceeded.

In general practice, well-rounded hatch corners are now arranged in dry cargo ships; and in tankers earlier undesirable details of framing structure and of bulkhead stiffening ending on "soft" plating have been eliminated. Fabricated sternframes are now designed with easy contours at their junction with the main hull at the orter.

Over recent years significant changes have taken place in the general design of merchant ships. The modern dry cargo carrier is of finer form than the older deep sea tramp. The three-island coal-burning type has been replaced by the two-deck or shelter-deck oil burner. There is, in result, a trend toward increased weight with decreased buoyancy at the ends. This is further accentuated in some faster cargo liners which also carry cargo in long forecastles and poops. Hogging moments in the loaded condition consequently tend to be more severe than those in cargo ships of a generation ago, for which sagging in ballast was the more critical condition.[46] In many welded ships the resulting compressive stresses in the bottom plating have led to the development of corrugated plating between transverse floors, a defect to which reference has already been made. The tensile stresses in the strength deck call for most careful design, particularly at hatch corners and other openings. Experience and experiment clearly indicate the advantages in the modern dry cargo ship of framing the bottom and strength deck longitudinally over the midship half length. This arrangement, which also considerably reduces steel weight, is being increasingly adopted and is in line with the now universally recognized system of framing in ocean-going tankers.

In modern tankers due to progress in general design, the ratio of tank length to ship length has been significantly increased. Loading can consequently be spread over a greater portion of the ship's length with a beneficial reduction in sagging moments. The ample tank capacity available provides good flexibility in cargo distribution, but this must be carefully controlled, especially in the big ships, to avoid undesirable stressing in service. The important influence of judicious cargo distribution in minimizing structural damage is increasingly recognized both for dry cargo ships and tankers; and guidance to owners has been made widely available in recent years.[47]

ACKNOWLEDGMENT

In conclusion, I wish to record appreciation of the assistance willingly given by many individuals and organizations in the preparation of this review, which presents so inadequate a picture of their work.

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WRC BULLETIN NO. 16

The WELDING RESEARCH COUNCIL has just issued its Bulletin No. 16 of its regular Bulletin Series. This Bulletin contains two reports:

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Inert-Arc Field Welding of Pressure Piping

The use of paper discs as backing strips in the inert-gas-shielded arc-welding process as applied to field erection of Pressure Piping

by R. T. Pursell

INTRODUCTION

For many years there have been various opinions expressed as to the quality and serviceability of the root conditions of circumferential butt-welded joints in pressure piping systems. Everyone engaged in the fabrication and erection of pressure piping has been confronted with this problem quite frequently. Those engaged in the welding of piping for the steam power plant industry have been using metallic backing rings of various shapes and sizes for the purpose of obtaining suitable root conditions, and it has proved to be satisfactory. However, many welding engineers have been experimenting with various other methods, with the hope of perfecting a technique that would produce satisfactory root conditions without the use of metallic backing rings. Such a technique must of course produce, first, an improved or more desirable condition than heretofore existed; second, it must be practicable both from a cost and quality standpoint; third, it must be adaptable to both shop fabrication and field erection.

Since the advent and development of the inert-gas-shielded arc-welding process, it definitely appears that through its use it is possible to progress a step closer to the perfection desired for root conditions of circumferential butt-welded joints in pressure piping systems. In using the inert-gas-shielded arc-welding process as a method for fusing together the root edges of the abutting piping without the use of metallic backing, it is possible to produce a very desirable condition. However, in place of metallic backing, it has been discovered by others as well as the writer that an inert gas backing improves the contour and general appearance of the internal portion of the root bead. The data published to date by others illustrate special fixtures which have been made up to hold the inert gas inside the pipe during welding. The results reported by using special fixtures were satisfactory for shop fabrication where it is possible to insert and remove such fixtures.

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The problems encountered in the field erection of pressure piping eliminate the possibility of using such fixtures; therefore, other methods of obtaining suitable inert gas backing for field erection must be used. The method developed and used by the writer with marked success employs the use of paper disks placed inside the piping and held in place with masking tape. The inert gas is inserted through a small hole in the welding groove. (See Figs. 1, 2 and 3.) The data included in this paper have been accumulated from a series of welding tests of various materials employing this principle as it would be applied to the field erection of pressure piping.

MATERIALS

The piping materials used are as follows: ASTM-A-280, 10.750 in. OD by 0.718-in. wall; ASTM-A-315, 10.750 in. OD by 1.125-in. wall; ASTM-A-158-P5a, 6.625 in. OD by 0.456-in. wall; and 25.0% Cr – 12.0% Ni centrifugally cast stainless-steel tubing, 4.500 in. OD by 0.540-in. wall.

PROCEDURE

In all cases, except as noted, argon gas backing was used. Prior to fitting the ends of the piping together, a paper disk is placed in each pipe, approximately 6 in. from the end, and held in place with masking tape. (See Fig. 3.) The ends of the pipe are then fitted together in the usual manner as shown in Fig. 1. A $^3/_{16}$-in. diam hole is drilled in the center of the welding groove and a copper tube attached to the argon gas supply is inserted through this hole into the pipe, as shown in Figs. 1 and 2. With the preheat temperature already attained, the backing gas supply is bled into the pipe and the first bead made by fusing together the root edges of the joint using the inert-gas-shielded arc-welding process; no filler metal is used. After this much of the weld is made, it is possible to inspect visually the inside condition by inserting an optical instrument through the hole used for inserting the backing gas. Any defects located are repaired by remelting these areas from the outside. When the inside condition is acceptable, the backing gas is applied again and the second bead deposited, using the same process and

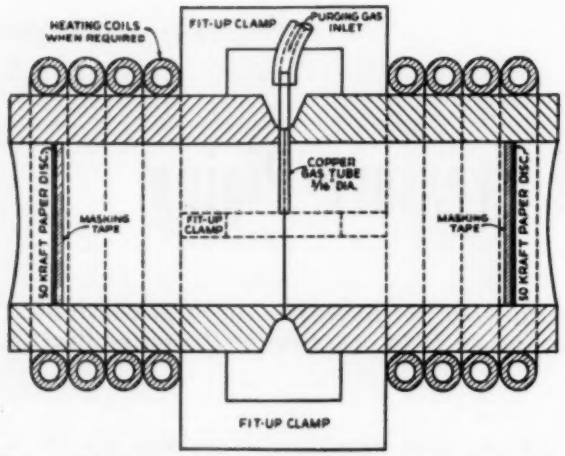


Fig. 1 Sketch showing a typical butt-joint setup illustrating the location of the paper disks and purging gas-inlet tube

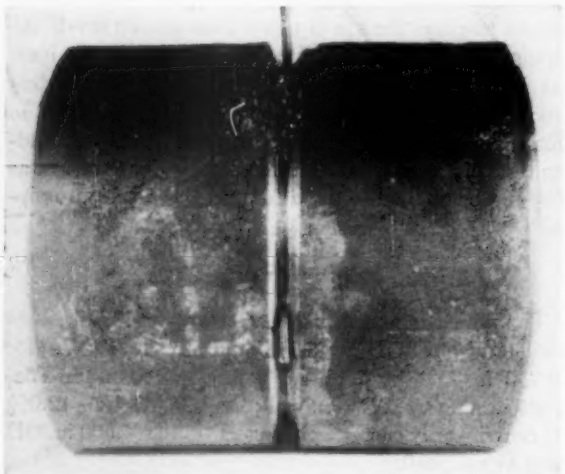
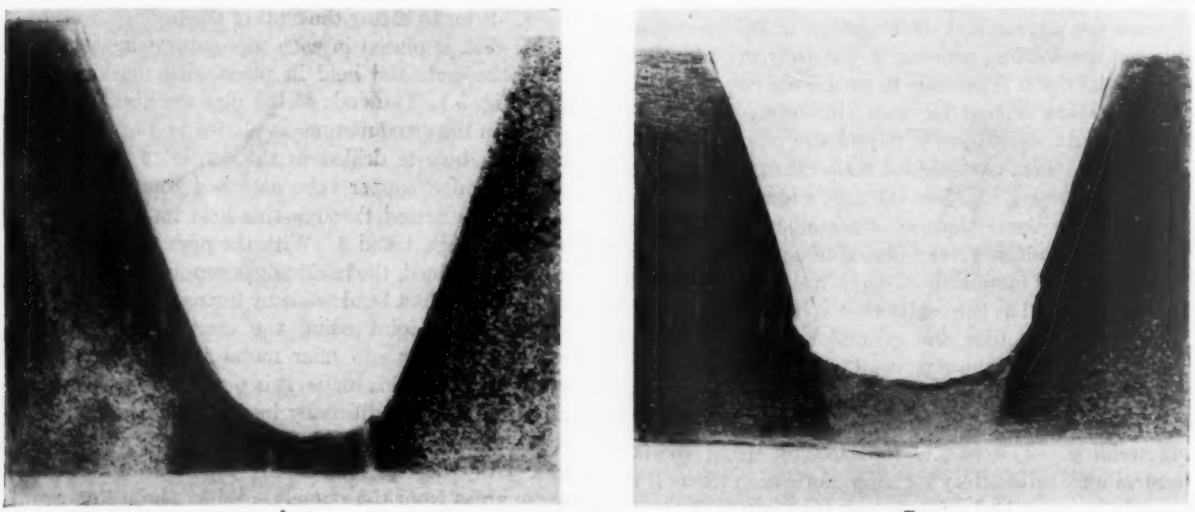


Fig. 2 Photograph showing the purging gas tube inserted in the pipe through the root of the welding groove

Fig. 3 An end view showing the paper disk, masking tape and the gas-inlet tube

adding filler metal. When the second bead is deposited, the visual inspection is performed again in order to be assured of an adequate root condition. Backing gas is bled into the pipe to fill the reservoir between the paper disks, the copper inlet tube is then removed and the hole welded closed using a filler rod, employing the inert-gas-shielded arc-welding process. This visual inspection is made while maintaining a preheat temperature of 150° F., in order to prevent harmful effects to the instrument.

By depositing a second bead with filler rod added, the root portion of the joint is more adequately prepared for the subsequent arc-welding process used for completing the welding of the joint. During the stress-relieving operation, the paper disks and masking tape burn up.



A B

Fig. 4 A, Macrospecimen showing the appearance of the first bead in the groove. B, Macrospecimen showing the appearance of the first two beads in the groove

Of the many tests performed on 50 Kraft brown wrapping paper, it was found that the tape and paper burn completely at a base metal temperature between 550 and 600° F. Therefore, all preheat temperatures were 400° F with a minimum of 350° F. All of the stress-relieving temperatures were 1350 ± 25° F.

TESTS AND OBSERVATIONS

A great many tests were made including cross-section macrospecimens, guided root and side bends, radiographs and photomicrographs. The observations of these tests reveal that results as good as, and in most cases superior to, those obtained by other methods, can readily and consistently be accomplished in shop fabrication or field erection of pressure piping.

All of the welding tests were made with the pipe in the horizontal fixed and vertical fixed positions; no tests were made using the horizontal rolled technique. All welds made with the pipe in the horizontal fixed position were deposited by welding upward.

Figure 4 shows two cross-section specimens illustrating the appearance of the first and second beads in the root of the groove. Figure 5 illustrates a cross section of a weld in 25.0% Cr – 12.0% Ni centrifugally cast stainless-steel tubing. The root pass was made by fusing the edges together with the inert-gas-shielded arc-welding process; no backing of any type was used; preheating and stress relieving were not employed in making this weld. Figure 6 illustrates a cross-section specimen of a weld in 4.0 to 6.0% Cr piping. The inside diameter of the pipe was not machined and, even though a misalignment at the root edges existed, satisfactory results were obtained. The root-bend specimens from this same weld, as shown in Fig. 8, reveal very satisfactory conditions. Figure 7 is a radiograph of a weld made in 25.0% Cr – 12.0% Ni tubing and illustrates that radiographically sound weld deposits with good root conditions can be produced by this welding technique. Figure 9 illustrates a few root-bend tests in A-280 pipe material revealing favorable root conditions. Figure 9A illustrates a few side-bend tests in A-280 pipe material, all of which indicate sound root conditions. Figure 10 illustrates a few root-bend tests with a slightly concave root bead contour. This type of root condition generally exists when welding in the overhead position. All of the root-bend tests performed with such root conditions produced satisfactory results, indicating that within reasonable limits such root bead conditions do not appreciably affect the quality of the welded joint. Figure 11 illustrates the general inside appearance of the root bead on A-315 pipe material. Figure 12 illustrates two photomicrographs at × 250; *B* is the inert-

Fig. 7 A radiograph of a weld made in 25.0% Cr – 12.0% Ni centrifugally cast stainless-steel tubing

Fig. 5 A macrospecimen of a weld in 25.0% Cr – 12.0% Ni centrifugally cast stainless-steel tubing

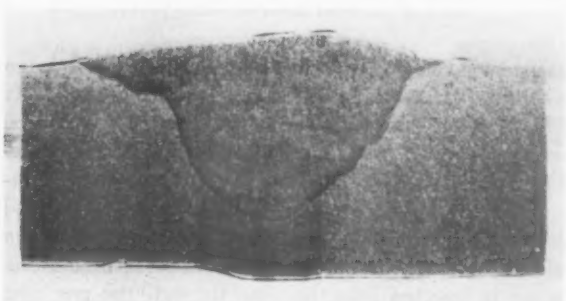


Fig. 6 A macrospecimen of a weld in 4.0–6.0% Cr piping

Fig. 8 Root-bend specimens of a weld in 4.0–6.0% Cr piping

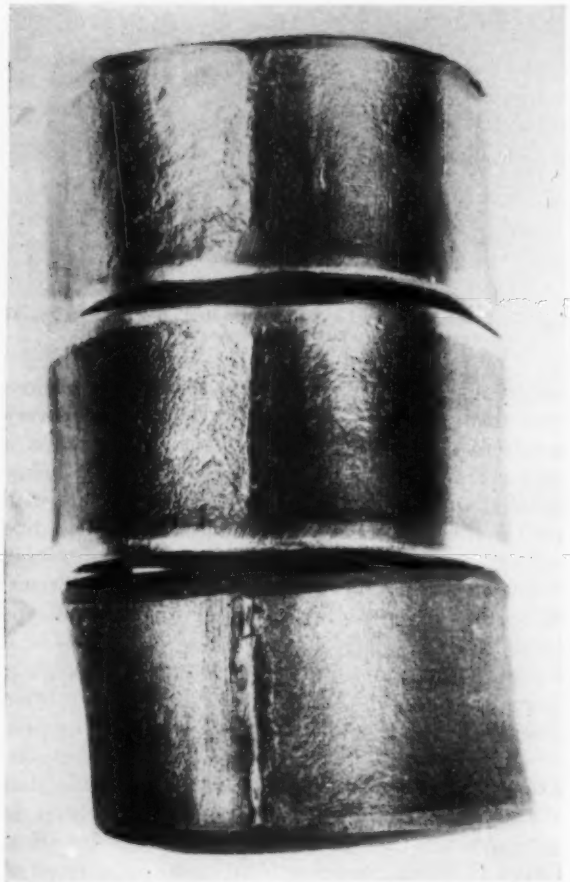


Fig. 9 A few root-bend specimens of welds in A-280 piping. Good root-bead conditions

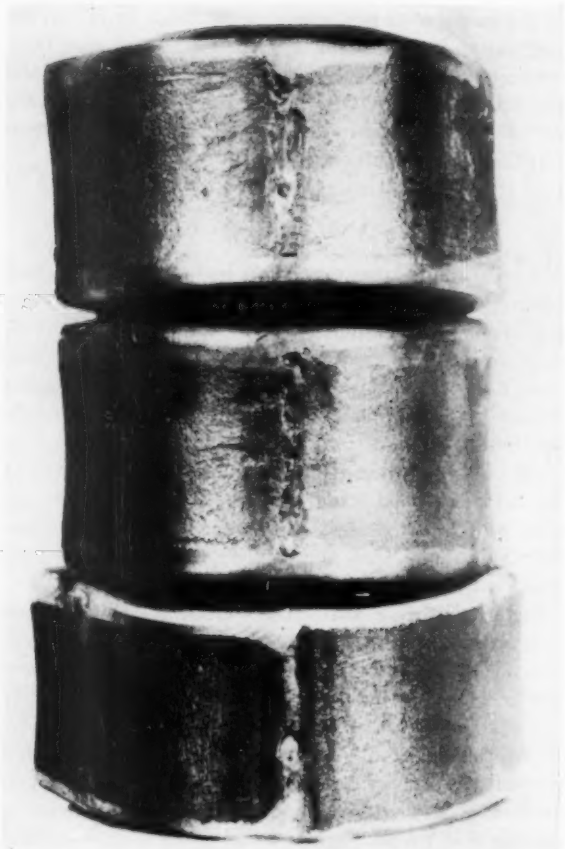


Fig. 10 A few root-bend specimens of welds in A-280 piping, illustrating acceptable results although the root-bead contour is slightly concave

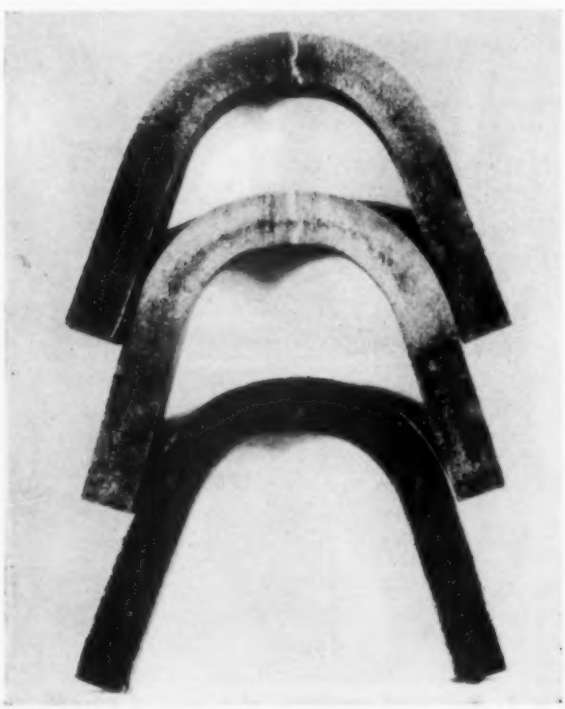


Fig. 9A Side-bend specimens, sound root conditions

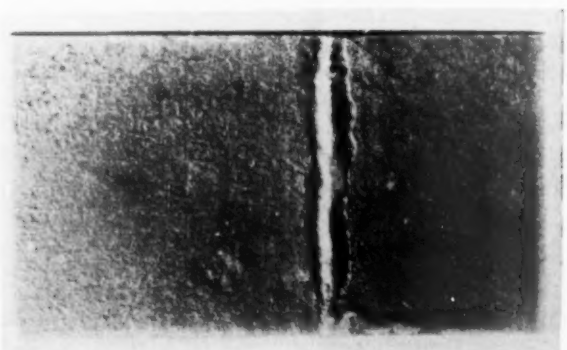
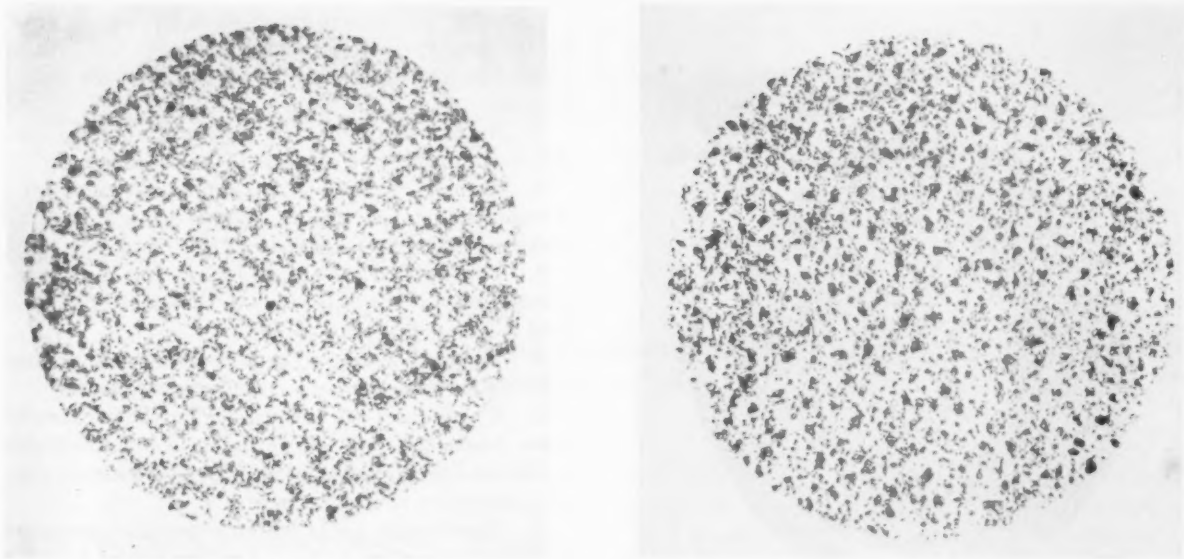


Fig. 11 Photograph illustrating the general inside appearance of the root bead in A-315 piping

gas-shielded arc bead before bending; *A* is the same weld after the guided-root-bend test was performed. It will be noted that very little difference, if any, can be detected in the weld metal structure after bending. Figure 13 is an illustration of the method used for inspecting the inside conditions of the inert-gas-shielded arc-welding bead before proceeding with the remainder of the welding. A commercially manufactured Borescope is inserted into the pipe through the gas inlet hole, thus permitting a visual inspection of the com-



A B

Fig. 12 A. Photomicrograph at ×250 of the same weld after the guided-root-bead test. B. Photomicrograph at ×250 of inert-gas-shielded arc bead before bending

plete internal condition of the weld. This method of inspection is very easily accomplished and can be performed while maintaining a preheat temperature of 150° F.

Table 1 illustrates the joint details and the inert-gas-shielded arc-welding technique employed for this work which since has been set up as a standard. These joint details can be used with or without backing rings and they conform to the details being used by the industry in general.

Table 1

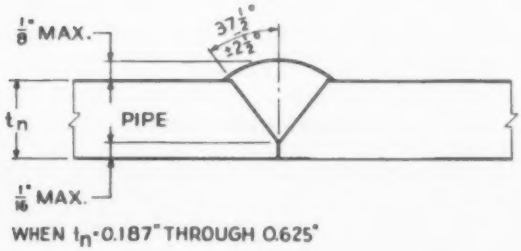


Figure A

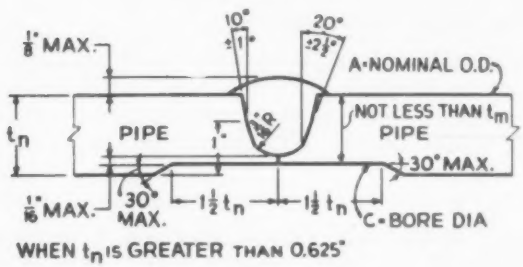


Figure B

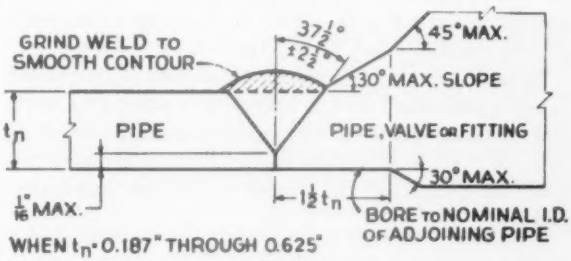


Figure C

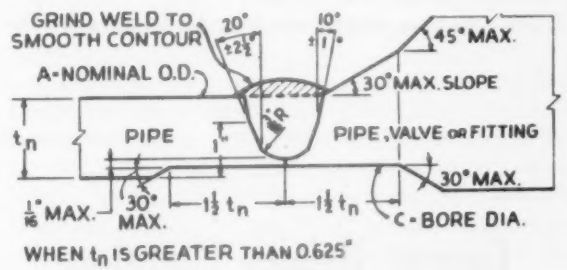


Figure D

INERT-GAS-SHIELDED ARC WELD

Beads	Filler rod, in.	*Tungsten electrode, in.	Gas† cup	Welding gas argon, cfh	Straight polarity, d-c I	V
1	None	3/32	4 or 5	8–10	140–150	12–14
2	3/32	3/32	4 or 5	10–12	150–160	14–16

Argon gas backing.
* Thoriated.
† Metal gas cups.

Fig. 13 An illustration of the instrument used for inspecting the inside surface of the root pass

Although all the welds described herein were performed with the ends of the piping butted together as shown in Table 1, several welds were made with the ends of the adjoining pipes spaced approximately $^1/_8$ in. apart. In such cases it is necessary to use a filler rod on the first pass and, even though the function of the backing gas is not as favorable as when the ends are together, the results are satisfactory.

In addition to the materials described herein, work is being performed by the author on copper, aluminum and austenitic stainless steel piping materials employing this same welding method and, although this work has not been completed, the results to date are quite satisfactory.

CONCLUSIONS

The following conclusions may be made as to the adaptability of the inert-gas-shielded arc-welding process for the purpose of improving the root conditions of circumferential butt-welded joints in pressure piping systems:

1. An improved and more desirable root bead condition can readily and consistently be produced.
2. Although sufficient cost figures have not been accumulated as yet, there is every indication that the cost for the quality produced will be favorable.
3. The method of accomplishing the results reported herein is adaptable to both shop fabrication and field erection of pressure piping.
4. The method used to inspect the inside root bead condition is easily performed and very satisfactory.
5. By retaining the backing gas for the first two or three beads, it is possible to obtain a more desirable inside condition than if the backing gas is removed after the completion of the first bead.
6. Pipe-to-pipe joints within reasonable tolerances (misalignment of $^1/_{16}$ to $^3/_{32}$ in.) can be welded together with satisfactory results. However, when joining valves or fittings to pipe, it may be necessary in some sizes and schedules to bore the pipe to within the limits specified herein.
7. When using the method employed herein for piping that does not require preheating and/or stress relieving, it would be necessary to heat the joint uniformly to 600° F in order to burn up the paper disks and tape. In general, this would not be an adverse requirement.

A patent application has been filed covering the apparatus and method used for inserting and retaining the backing gas as illustrated in Fig. 1 herein.

ACKNOWLEDGMENT

The author wishes to express his gratitude to Stone & Webster Engineering Corp. for the permission to present this article, to those members of the Stone & Webster Welding Engineering Laboratory who made the many tests described in this paper, and to E. H. Krieg for his helpful suggestions.

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(*Continued from page 22*)

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Faster Fusion

How an aeronautical company selects the advantages of shielded arc welding to meet production requirements

by J. R. Fullerton

A REVOLUTION in fusion welding has taken place at Ryan. During World War II, we "stitched" thousands of aircraft and engine components together with acetylene gas, atomic hydrogen and metallic arc welding. Today, only metallic arc remains as a member of this fusion welding team.

The big switch has been to a newer method: inert-gas-shielded arc welding, and we have converted all acetylene gas and atomic hydrogen production facilities to this technique. Ryan's 169 fusion welding stations consume more than two million cubic feet of inert gas a year to make it one of the nation's largest users of this process.

Fusion welding is the most versatile and useful tool which modern industry has evolved since the days of the village blacksmith. In countless applications it has replaced fastening by bolts and rivets and made possible new structural designs. This is particularly true in the high temperature products which our company builds for jet, rocket and piston engines. Here, the hurricane of heat which they must endure requires that they be as homogeneous as possible. Also, the supersonic flows of fluid through them demand smooth projection-free surfaces to avoid the incidence of turbulence and drag. Inert-gas-shielded arc welding incorporates the advantages of other types of fusion welding and permits the joining of many high-temperature "superalloys" which could not otherwise be fabricated.

New developments in this field have been so numerous that it might be well to unscramble some of the confusion which may exist in the layman's mind. There are five basic types of shielded arc welding in general use. These are: (1) Inert-gas-shielded tungsten arc welding, (2) inert-gas-shielded metal-arc welding, (3) submerged arc welding, (4) atomic hydrogen welding and (5) coated electrode arc welding.

All of these methods employ the use of a shielding agent, either gas or solid, to protect the hot electrode and weld metals from the oxidizing effects of the atmosphere. While this oxidation can be tolerated in many industrial welding applications, it is thoroughly undesirable in aircraft structures. In jet, rocket and piston engine parts, oxidation produces a brittle, porous structure with reduced strength and corrosion resistance. Continually subjected to cyclic extremes in heating and cooling, these components must be joined by top quality welds. Similarly, aluminum and magnesium alloy structures must be shielded from oxidation when welded or the hard oxide film which forms will prevent the heating and joining of the metal.

INERT-GAS-SHIELDED TUNGSTEN AND WELDING

Developed at the General Electric Co. by Hobart and Devers, inert-gas-shielded tungsten arc welding is similar to atomic hydrogen welding in that it makes use of a gas for protecting the hot metal. Unlike the atomic hydrogen process, the arc is maintained between a single tungsten electrode and the base metal instead of between two electrodes. Also, the blanketing gas, which flows in a low velocity stream around the electrode, consists of an inert, monatomic gas rather than hydrogen. This gas serves only as a shielding agent and does not dissociate to release additional heat as hydrogen does.

The heliarc arc is quiet and the tungsten electrode consumption is extremely low. Filler rod may be added by simply feeding wire into the arc. Both a-c and d-c systems are used depending upon the materials being joined. Argon and helium- shielded tungsten displays a marked polarity, or rectifying quality. When used with d-c current, this causes unequal heating at the two ends of the arc. With straight polarity, the electrode operates cool and the work is hot, which is desirable for most metals. For use with aluminum, magnesium or berrylium-copper alloys, however, reverse polarity must be employed, in which the electrode is positive and operates hot with the work cooler.

The outstanding advantages of inert-tungsten arc welding are elimination of flux, increased speed, improved quality and minimized weld finishing. By elimi-

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Fig. 1 In a Ryan-built rotating fixture, the operator welds a heavy jet-engine burner plate with the submerged arc process. The arc is avalanched in powdered flux

nating the need for flux, this method provided the first successful means for fusion welding aluminum and magnesium alloys which are attacked by the corrosive elements of fluxes. Without flux, flux entrapment is avoided. This permitted much more latitude in welding design because some joints are certain to entrap flux and often its removal is impossible. Ryan employs inert tungsten arc to weld tee, lap and edge joints which were formerly regarded as impractical because of flux removal problems.

The method is fast. Full penetration with speeds as high as 40 ipm can be attained on $^1/_{16}$-in. stock. The pinpoint concentration of heat which this method provides, coupled with its speed, makes it exceptionally useful for welding stainless steels. These alloys are subject to carbide precipitation and loss of corrosion resistance when exposed to sustained welding temperatures. Also, the stabilizing elements of columbium and titanium, contained in stabilized grades of stainless steel, may be boiled away if the metals are held at welding temperatures for prolonged periods.

Undoubtedly, the inert tungsten arc narrow band and high-speed heating characteristics have made possible the welding of the superalloys, used in jet engines. Inconel X and W, Stellite 25 and N-155 are extremely susceptible to cracks at welding temperatures because of their poor thermal conductivity and high coefficients of expansion. Normal welding techniques pour heat into these alloys faster than they can conduct it away from the weld zone. As a result, extreme temperature differential is established between the hot and cold portions of the sheet and severe stresses are set up. The inert tungsten arc avoids these phenomena because of its speed and narrow zone of heating.

The method is efficient for welding practically all of the commercial metals including aluminum, magnesium, copper, titanium, stainless steels, nickel and cobalt base alloys, carbon steels, cast iron, lead and silver. It produces X-ray quality welds which possess good tensile strength, elongation and impact resistance. Its high speed makes it ideal for welding light-gage materials because it reduces warpage and provides attractive appearing welds. At Ryan, this method is used to weld gage thicknesses running from 0.035 in. to two sheets of 0.156 in.

Due to its inherent characteristics and the stabilizing effect of the blanketing gas, the weld deposit is laid down in a smooth bead without sputter or splash. Consequently, the weld seldom requires the grinding or finishing operations which are associated with other fusion welding operations. This is a distinct advantage in reducing labor costs and production time.

Ryan rolls all inert-tungsten-arc butt welds in austenitic steels, which are accomplished without the addition of filler wire, in seam rollers. Especially built for this work, the machines flatten the weld seam between two steel rolls under heavy pressure. This cold works the weld to refine its structure and eliminates the notch effect caused by the tendency of the metal to sag slightly when molten.

All exhaust systems are fabricated with inert-tungsten arc welding. Covering about 80% of the industry's requirements, these structures serve such prominent aircraft as Douglas DC-6 and C-124 Globemaster II transports, Boeing B-50 Superfortress, C-97 Strato-

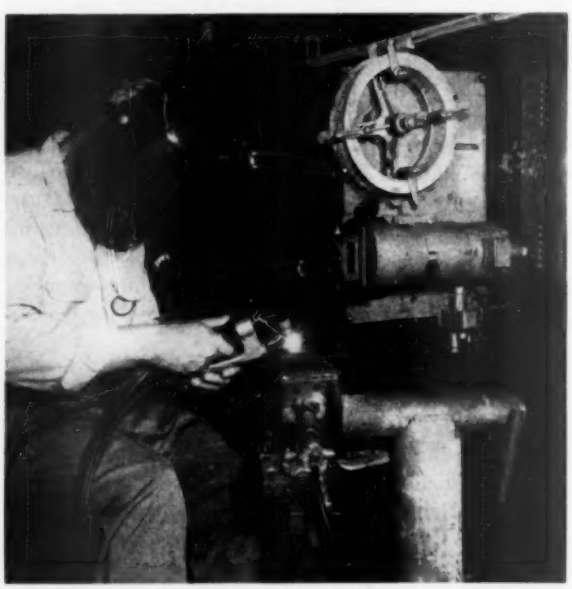


Fig. 2 Welding supervisor uses the newest technique to weld exhaust system parts. Combining the speed of automatic welding with the control of manual methods, the new machine feeds wire into the arc between motor-driven rolls

freighter and 377 Stratocruiser aircraft, Convair 240 and 340 airlines, Piasecki helicopter and Fairchild C-119 "Flying Boxcars." Ryan manifolds are also used on General Patton M-47 and M-48 medium tank engines. These structures are fabricated from Inconel, and stainless steel of 19–9DL, 347, 321 and 310 types. Gages run from 0.042 to 0.095 in.

Because of the complex, irregular design of these exhaust systems, they are welded manually. The method is well adapted to this work because it involves lightweight equipment with some torches weighing only 3 oz. For this work we have established one of the most modern welding areas in the aircraft industry with 29 integrated inert-tungsten arc-welding booths in one location. All motor generators are installed overhead and a cascade system is used to supply argon gas and cooling water. Gas and water are automatically controlled by timers.

For these tasks, d-c straight polarity current, ranging from 75 to 100 amp, is used. Material thicknesses vary in the designs and the welder uses a Mullenbach foot control rheostat to vary the welding voltage as he goes. This allows the welder to attain better control of welding conditions and produce a finer weld result.

Instead of adding filler metal to these welds, an upstanding flange is formed at the seams and melted down by the heat of the inert-tungsten arc.

We also use manual inert tungsten arc methods to weld a wide variety of detailed components for General Electric, Westinghouse and Pratt and Whitney jet engines. These run the gamut of special alloys such as Inconel, Inconel X and W, Stellite 25, N-155, Discalloy and the stainless steels. In jet engine work, an added requirement is made. The dimensions of the weld are specified and tolerances in width must be closely controlled.

In addition to the high-temperature alloys, Ryan welds many aluminum alloys with manually controlled inert-tungsten arc. Typical example of this work is the welding of huge fuel tank rings, 4 ft in diameter. These rings serve as splice joints for the largest external fuel tanks ever built for aircraft. They are fabricated from 61S aluminum alloy with high-frequency stabilized a-c current, using between 75 and 150 amp, depending upon thicknesses encountered. These gages vary from 0.050 to 0.072 in. The torches used are exactly the same as those employed in welding stainless steels.

One of the interesting types of welding which only inert-tungsten arc is fitted to accomplish is fusion spot welding. With a special Linde pistol-type torch, the method can be used to make automatically timed spot welds which are exceptionally useful in certain production jobs. Because the spot welds can be accomplished from only one side of the structure, the parts do not need to be removed from jigs but can be spot welded right in their fixtures. The technique is valuable where several components must be aligned in a precision fixture and spot welded in place.

Ryan has constructed a mobile machine which incorporates all of the necessary elements for inert-tungsten arc spot welding—d-c generator, argon gas supply, 40-gal water tank and pump. With this device, spot-welding facility can be quickly moved along the production lines to the work We are using the new machine to spot weld Fairchild C-119B exhaust hoods and machined rings in assembly jigs. After these parts are carefully fitted together and spot welded, they are seam welded in resistance-welding machines. The torch produces such a smooth spot weld that no finishing is necessary in order to run these parts between the wheel electrodes of the resistance welders.

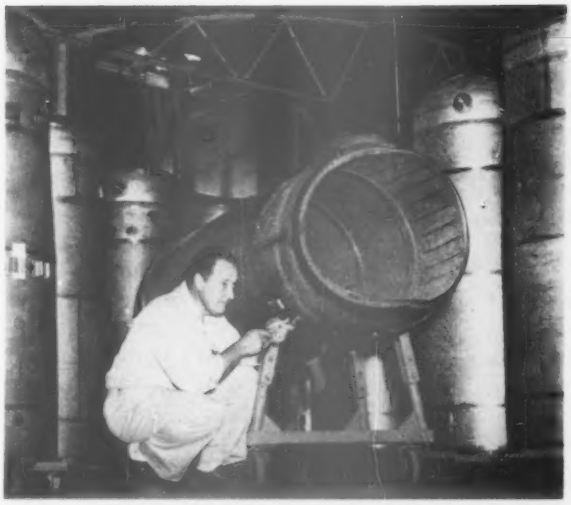


Fig. 3 Like mammoth "flame throwers" for General Electric jet engines, these afterburners must be Heliarc welded into smooth barrels of Inconel W

In addition to the large amounts of manual inert-tungsten arc welding, substantial quantities of automatic are accomplished. Automatic machines are used on all straight-line, butt-welding jobs, both in aluminum alloys and the stainless steels. For instance, we build afterburners, tail pipes and exhaust cones for General Electric J-47 jet engines in this way. These structures are fabricated from stainless steels and other high-temperature alloys in thicknesses from 0.040 to

Fig. 4 Aircraft engine exhaust systems are Heliarc welded at Ryan in one of the industry's most modern facilities. Consisting of 29 welding booths equipped with overhead machines, remote controls and automatic argon gas and water controls, the unique arrangement has substantially increased production

0.075 in. We design and build special fixtures to hold the parts in exact alignment while the automatic inert-tungsten arc-welding head traverses their longitudinal or circumferential seams. D-C straight polarity current is used and welding speeds up to 30 ipm are attained. A number of machines are equipped with selenium-type rectifiers which convert a-c current from the line into d-c and eliminate the motor generator.

All of the longitudinal seams in huge fuel tanks are welded with automatic machines. These large sections are butt welded with filler wire automatically fed into the seam. The alloy is 61S aluminum and gage thicknesses run from 0.051 to 0.072 in. With the Airco "floating" head which automatically maintains a constant length arc, it is possible to weld contoured surfaces. We have built such a machine and use it to weld the irregular contours of afterburner nozzles automatically.

One of the newest devices, which we are using, is the Linde semiautomatic HWM-1 welder. This is a manually operated Heliarc torch which automatically feeds filler wire into the arc. All the operator has to do is set the current and wire feed and guide the work. When the arc is struck, the wire is automatically fed between rolls into the weld. Its movement propels the torch. Hand welding speeds as high as 80 ipm have been reached with this new method. Combining the advantages of manual guidance with automatic control of arc length, wire feed and travel, this technique is excellent for irregular components. It is water cooled and capable of handling up to 300 amp capacity.

We use a great deal more argon gas than helium in connection with inert tungsten welding. Basically, this is because argon can be obtained in higher purity commercially and is more efficient for most of the welding tasks. Ten times heavier than helium, argon flows down over the welding better and much less is required to perform a similar welding assignment. Argon arcs have lower voltages than helium arcs and thus permit the use of higher currents without burning the work. Both lower voltage and increased current contribute to improve arc stability. Ryan does use helium, mixed with argon, for all welding of aluminum alloys because the heat of the helium arc is greater for a given current than that of argon and penetration is deeper.

INERT-GAS-SHIELDED METAL-ARC WELDING

For speed in welding, inert-gas-shielded metal arc—sigma—makes other types look slow. This amazing method has been clocked at 200 ipm with $^1/_{16}$-in. material. Even in $^1/_2$-in. plate, structural welds can be made at 48 ipm.

Sigma uses a consumable wire electrode which is fed at high speed through a blanket of argon gas and melted into the weld area. Like the inert tungsten arc, it produces high-quality welds with deep penetration and lends itself to automatic operation. Sigma welding can handle twice the current densities which are used with Heliarc.

Fig. 5 An electronic "eye" calls "time" on sigma welding machine which has squeezed the time for welding an exhaust system nipple from 3 min to only 7 sec. Machines employs a fast-shift carriage and automatic operation

Sigma is used to weld exhaust system nipples to port flanges and join ball sections to exhaust tubes. These components are about $2^1/_2$ in. in diameter and are welded circumferentially. For welding the nipples to the flanges we have devised a new machine which is phenomenal in its effectiveness.

The welding unit used is a Linde FSM-1 type powered by a Lincoln 400-A motor generator. The unit is mounted on a custom-built fixture which incorporates a sliding carriage with two revolving holders that term at constant speed. Each holder is a small expanding mandrel which firmly retains the nipple during welding and quickly releases it when contracted. The carriage moves back and forth through an 18-in. travel to bring the nipples directly under electrode of the sigma welder. It is operated by foot pedal control.

The operational sequence goes like this: The operator places a nipple on one of the revolving holders and presses the foot pedal. The carriage shifts to bring the nipple under the electrode. As it moves, the carriage trips a microswitch which starts the welding cycle and the arc strikes. Current used is 250 amp, reverse polarity d-c. The light of the arc plays upon a photoelectric cell which trips a relay that automatically times the welding run and switches off the arc. All the operator has to do is shift the carriage and replace the nipples. With two holders, one nipple is being welded while the other one is being replaced by the operator.

Formerly it required 3 min of manual welding plus finishing to do one of these nipples. With the new machine it takes only 7 sec to attain a sound, clean weld which requires no cleaning or finishing labor. A normal production for this machine is 800 nipples per 8-hr shift although as many as 1200 have been accom-

plished in that period. Ryan exhaust system production uses thousands of these stainless steel components and it is quite evident that the new machine has substantially reduced their cost and increased their availability.

SUBMERGED ARC WELDING

The submerged arc welding technique is similar to sigma welding in that it also employs a consumable electrode and permits the use of high current densities. It is different in that the shielding agent is not a gas but consists of dry, granular flux which pours down over the weld area. The arc and weld metal are fully protected from oxidation by this means. The granular flux melts and forms a fused slag which blankets the weld. The material which does not melt is recaptured and used again. The solidified slag is easily removed from the weld.

With the submerged arc there is no arc visible and the operation is quiet and smooth. Because the submerged arc permits the use of higher density currents much larger diameter electrodes can be used and heavier welds laid down in single passes. For this reason, it is used to weld heavy gage materials and lends itself to straight-away work. Speed is a salient feature of submerged arc. Automatic machines can weld metals 3 in. thick in one pass and can attain 200 ipm on light-gage materials.

Automatic submerged arc is used to weld a large heavy-gage circular burner plate and flange together. This assembly is part of the aft frame, or "backbone," of General Electric J-47 jet engines. The big burner plate is 0.125 in. thick and the flange is 0.075 in. Both components are fabricated from 321 stainless steel. The work is performed on a specially built fixture which is rotated by means of a large Worthington weld positioner. Filler wire of 29–9 composition is added to the weld. Speeds of welding are 55 ipm to produce a $^1/_8$-in. fillet weld on one pass.

Fig. 6 Speeding at 30 ipm, an automatic Heliarc welding machine fuses the seam of a stainless steel tail pipe for a General Electric jet engine

Submerged arc is employed to weld stainless steels, carbon steels, Monel, Inconel, aluminum-bronze, copper-silicon alloys and straight chrome and nickel. Smooth, sound welds can be made at good speeds with 20 lb of metal per hour deposited.

Welded Bumpers, Profitable Item

EAGLE Motors, one of the largest automobile body repair shops in the Jamestown, N. Y., area salvages bumper sections from wrecked automobiles and uses electric arc welding to produce practically new bumpers for others. New bumpers, for instance, might cost around $67 for a large car, but if an end of the old bumper can be cut off and the remainder joined by welding to a salvaged end, the motorist pays only about $15, plus perhaps three hours labor costs. Approximately two-thirds of the new bumper cost is saved for the car owner this way, and Eagle Motors profits from salvaged materials and satisfied customers.

Typical salvaged bumper end is shown (right) while welder works on completing another bumper that sits up on bumper guard, is held with squeeze clamp for welding

Two passes at from 110 to 120 amp do the job with little metal preparation other than brushing; labor total includes disassembly, cutting, welding, painting weld (covered by guard).

Rebuilding and Repairing in the Auto Shop

Keep them rolling with your oxy-acetylene blowpipe

by L. B. Richmann

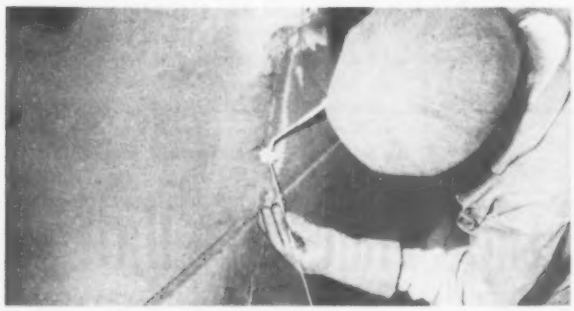
AN ESTIMATED 54 million cars, trucks and busses jam the nation's highways. In total they will travel approximately 490 billion miles this year. Normal wear on this vast fleet of vehicles coupled with damage resulting from accidents will keep garage repair and body shops busy. The shop that will profit most is the one equipped to handle all types of repairing and rebuilding with oxy-acetylene equipment.

Braze welding, bronze surfacing, fusion welding, hand cutting, soldering and heating and straightening are all used to restore cars to good working order. Worn and broken parts can be rebuilt, torn metal can be cut out and new sections welded in place, dents can be smoothed with body solder, worn battery terminals can be built up by lead welding and electrical connections can be soldered with your oxy-acetylene blowpipe.

L. B. Richmann, Linde Air Products Co.

A rip in a rear side panel is fixed by cutting out the damaged section and replacing it with new metal. Remove seats, carpet and upholstery to prevent burning them. The line of cut should be traced first to simplify the job

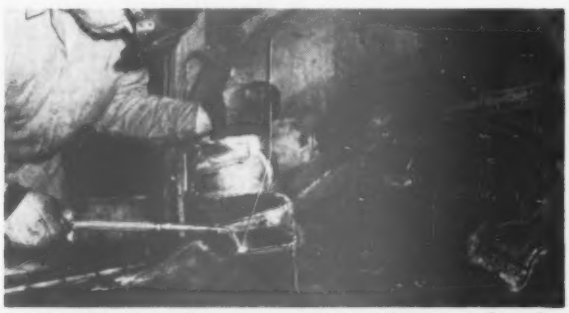
Braze welding also is a quick and easy method for rebuilding worn surfaces. Worn threads in the bolt holes of this cast-iron brake drum were repaired by filling in the holes with bronze rod metal and then redrilling and tapping



Fusion welding is used to join the new panel to the car body. After welding, the seam is ground and filed down and body solder is smoothed over the area to assure a smooth, even surface. Keep a fire extinguisher handy to assure safety

This brake connector arm became too worn for dependable use. Rather than buy a costly new part, braze welding was used to rebuild the worn surface. Braze welding is particularly useful in such repairs since the part gets little heat and there is no distortion

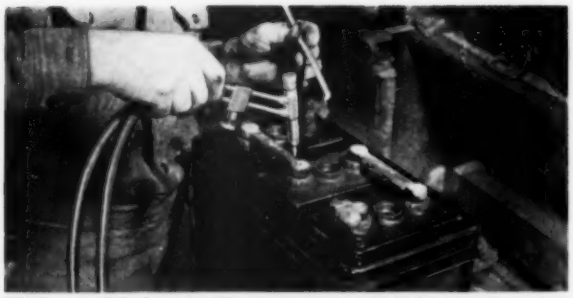
An air-acetylene torch makes body soldering easy. Straighten dents as much as possible by hammering. Then clean with a wire brush. Paint with muriatic acid and heat. After the second acid painting, flow on stick solder, heat to a pasty condition and smooth



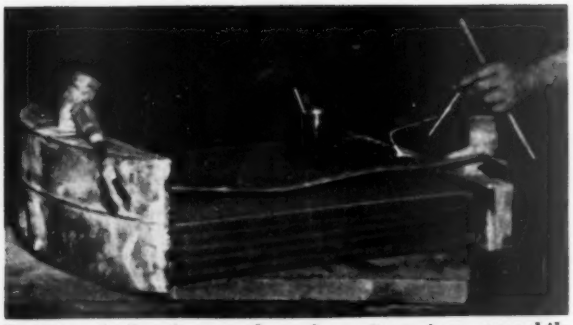
Steel welding used here to repair a floor panel makes strong repairs around braces and bolt holes. Note the absence of seat and carpet around the weld area to prevent a fire. Oil and grease must also be cleaned off with a wire brush or sandpaper

Braze welding makes a strong, easy repair of a 9-in. crack in a cast-iron cylinder block. The weld was started at the right and then allowed to cool after proceeding for 1½–2 in. Weld was restarted at left and completed in 2-in. segments

After cracks in a rear axle housing are fusion welded, the housing is reinforced with a fillet-welded sleeve. The sleeve is flame-cut from steel plate, heated with a blowpipe and hammered to a close fit. Here a weld is being made between sleeve and housing



With a mold obtained from any auto supply store you can build up a worn battery terminal so that the cable will hold tight. Clean off any battery acid deposits by scraping the parts bright. Then place the mold around the part and apply lead welding rod to fill it



Radiator leaks also can be a large item in automobile repair. An oxy-acetylene blowpipe or an air-acetylene torch is particularly handy for those leaks that are difficult to reach with a soldering iron. Here an oxy-acetylene blowpipe provides heat for the soldering job

Shaft Repaired in Half the Time at Half the Cost

▸ *Metallizing replaces brazing in repair of knitting-machine shafts*

"HAVEN'T had to buy a new rocker shaft since we purchased our metallizing installation in 1944," says the plant engineer of a large Virginia textile plant. The shaft is 2-in. in diameter and 15 ft long and is used to control the up-and-down motion of the "heddle" in a knitting machine. The rocker shaft, which is made of cold-rolled steel, moves back and forth in five cast-iron bearings, each approximately 3 in. long, and is controlled by a rocker arm held fast to the shaft with a dowel pin. They normally wear on all five bearing areas and can cause inefficient operation unless repaired or replaced. They can be reversed once as indicated by the drawing.

Each of the worn areas are turned down 1/8 in. on the diameter, rough threaded with a Rex AAA carbide tool and metallized with a 25 carbon steel, using 1/8-in. wire in a Metco 2E gun. The metallized areas are then turned down to the original 2 in. diameter.

Before they began using metallizing they would braze the worn areas on the rocker shafts, but this took twice the time and cost twice as much for materials. This metallizing user stated that a new shaft cost about $80, but that none had been purchased since they began using metallizing in 1944.

Taken from *Metco News*, Vol. 6, No. 6, published by Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

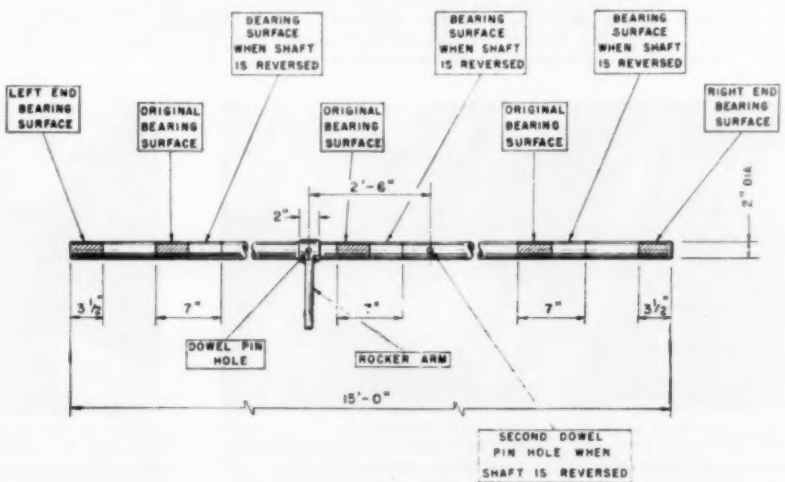


Figure 1

the AMERICAN WELDING SOCIETY

activities • related events

Why Come to Buffalo?

At the AWS Welding show, May 5 to 7, 1954, in the Memorial Auditorium in Buffalo, N. Y., where every booth will display, and many will demonstrate, every type of arc, gas, resistance and combined process welding apparatus, equipment and machines, the exhibits will be arranged in the AWS Continuous Display Plan which assures everyone seeing every exhibit with the maximum convenience and comfort, in the minimum amount of time, and with the minimum amount of walking. It will be an *all-welding* show in every square foot.

At the AWS Technical Meet, May 4 to 7, 1954, at the Hotel Statler in Buffalo, the country's leading welding and welding engineering authorities will present a program of technical and industrial "know-how" papers treating with every phase of welding, welding engineering, welding procedure, welding metallurgy and weldable metals. The subjects to be presented and discussed will be of both national and regional aspect, with many of specialized interest to industries within a 500-mile radius of Buffalo, in the United States and Canada. In addition, plant tours to leading industrial plants of the Niagara Frontier will be programmed.

In the Memorial Aditorium, under one roof, on one floor, in but several hours, the designer or the purchasing director, the management or plant executive, the engineer or the metallurgist, the supervisor, inspector or the welder, will see exhibited and demonstrated every type of arc, gas, resistance and combined process welding machine, equipment and apparatus offered by one of America's fastest growing industries.

In Buffalo both at the AWS Weldshow and Technical Meet, industry will learn how and where, right now, modern welding, brazing, cutting, heating and surface treating processes can save their user thousands of dollars annually and result in the producing of products having reduced weight, greater strength, lower unit cost, lesser mass and superior quality; products which possess the smooth line and pleasing contours attainable only by welding; products with the "eye-appeal" which creates "buyer-appeal."

See you at the AWS Weldshow and Technical Meet. J.G.M.

Come To The AWS Spring Technical Meeting

Buffalo, N. Y. May 4–7, 1954

Laws, Ordinances and Standards Relating to Welding

State and municipal government bodies and industry associations quite often feel it desirable to draft laws, ordinances or standards involving welding. Many of these are intended to promote the safety and health of those engaged in the welding operations. Others have to do with requirements and procedures when welding on important structures.

Quite often the authors of these laws, ordinances and standards are not well informed with respect to the Codes of the AMERICAN WELDING SOCIETY dealing with the same subject matter and would welcome advice as to such AWS Codes. Obviously, authors must consider and include the experience and know-how of the industry involved if they are to write a law, ordinance or standard that will accomplish its intended purpose most effectively and not be unduly burdensome or restrictive.

As an example of effective and pleasant cooperation, an Ordinance dealing with welding and cutting in the repair of tanks which have held combustible materials was recently proposed for adoption by the Buffalo City Council. When advised of this proposed Ordinance by AWS headquarters, the Niagara Frontier Section of AWS appointed a local committee which is now cooperating with the Buffalo governmental authorities. For the most part the subject matter of the proposed Buffalo Ordinance is covered by the AWS pamphlet "Safe Practices for Welding and Cutting Containers That Have Held Combustibles." AWS has similarly participated in other matters relating to safety, welder certification and to the welding provisions of building codes, to mention a few other subjects.

Member of the SOCIETY are urged to advise Headquarters of any proposed legislation, regulations or standards relating to welding that come to their attention. As in the past, each such matter will be carefully studied to make sure that welding is to be used as safely and effectively as possible. The national SOCIETY will cooperate with Local Sections and other interested groups to the end that those most qualified can assist in arriving at the best solution.

Address all communications, giving as much information as available, to Chairman, Public Relations Committee, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Financial Report

Auditor's Report

DAVID JOSEPH & COMPANY
Accountants and Auditors
17 E. 49th St.
New York 17, N. Y.

Oct. 6, 1953

AMERICAN WELDING SOCIETY
33 W. 39th St.
New York, N. Y.

Sirs:

We present herewith our report on the status of the SOCIETY's finances as at Aug. 31, 1953 and the results of operations for the fiscal year then ended.

Operations for the year resulted in an excess of income over expense in the amount of $22,234.92 as against $10,957.07 for the preceding year. This result was accomplished by an increase in the SOCIETY's total income to $348,636.68, an increase over the prior year in the amount of $77,036.90 while corresponding expenses were increased in the amount of $65,758.05.

Income from Membership Dues increased by $16,261.00 over the preceding year. Income from this source before allocation of Dues Income to JOURNAL Subscriptions amounted to $143,206, the registered membership having increased from 7937 to 9349. JOURNAL Advertising revenue for the year was $86,828 as compared with $69,012 for the preceding year. Included in this year's revenue for the first time was income from the National Spring Meeting Activity in the amount of $32,279. However, the direct expenses attributable to this latter activity amounted to $30,409.

The comparison of budget against actual operations shows that actual revenue exceeded budgeted revenue by $62,786, this excess being accounted for principally by the above increases in Membership Dues, JOURNAL Advertising and Spring Meeting Activity. The principal sources of increases in budgeted expenses were JOURNAL Advertising expense and the Costs of the Spring Meeting. Actual expenses thus exceeded budgeted expenses by $41,118.

As a result of this year's activities, the operating funds of the SOCIETY as at Aug. 31, 1953 amounted to $59,528.62 as against $37,293.70 at the corresponding date in 1952; and the funds in the Reserve Funds Committee Accounts amounted to $122,144.98 as against $115,932.17 last year. Total combined Resources of the SOCIETY on Aug. 31, 1953 amounted to $181,956.17 as against $153,624.30 last year. Total combined Resources of the SOCIETY on Aug. 31, 1953 amounted to $181,956.17 as against $153,624.30 on Aug. 31, 1952.

We herewith certify that the Statement of Assets and Liabilities and the Statement of Resources submitted herewith fairly present the financial status of the SOCIETY on Aug. 31, 1953 and that the Statement of Income and Expenses correctly sets forth the results of operations for the year then ended on a basis consistent with that of preceding years.

Very truly yours,
(Signed) David Joseph
David Joseph & Co.

January 1954

AMERICAN WELDING SOCIETY
Statement of Income and Expenses
for the Fiscal Year Ended
Aug. 31, 1953

Income:		
Membership Dues	$143,206.84	
Less: Amount Allocated to Subscriptions	20,198.22	$123,008.62
JOURNAL Advertising		86,828.06
JOURNAL Supplements		5,811.51
JOURNAL Cuts		2,969.79
Dues Income Allocated to JOURNAL Subscriptions		20,198.22
Subscriptions & Sales of JOURNALS		19,038.60
JOURNAL Reprints		10,075.08
National Meeting—Fall, 1952		13,065.58
National Meeting—Spring, 1953		32,279.40
Codes, Standards and Binders		7,678.61
AWS Educational Books		521.31
Welding Metallurgy Books		5,128.03
WELDING HANDBOOKS		16,302.87
Chapter Reprints—WELDING HANDBOOK		550.00
Weldability of Steels		689.00
Other Educational Books		2,717.86
Emblems and Certificates		885.65
Interest Income		888.49
TOTAL INCOME		$348,636.68

Expenses:		
JOURNAL Text Matter and Advertising Expense	119,080.93	
Technical Activity & Printed Matter	30,258.43	
Membership	40,191.69	
Education	2,580.03	
HANDBOOK	7,877.35	
National Meetings	56,638.92	
Administration	4,866.76	
Section Refunds	32,570.56	
AWS Educational Books	253.74	
Other Educational Books	2,319.15	
JOURNAL Reprints	6,404.96	
Emblems and Certificates	516.74	
WELDING METALLURGY Books	3,729.68	
Weldability of Steels	500.00	
Purchase of Equipment	3,460.04	
Awards	553.14	
Yearbook and Membership Directory	4,740.89	
Publicity	785.40	
Employees Insurance Expense	5,586.98	
1% of Gross Income to Reserve Funds Account	3,486.37	
TOTAL EXPENSES		$326,401.76
EXCESS OF INCOME OVER EXPENSE		$ 22,234.92

Cleveland Meeting Highlights

The Thirty-Fourth Annual Meeting of the AMERICAN WELDING SOCIETY and the Thirty-Fifth National Metal Exposition held in Cleveland during the week of October 19th were outstanding successes from start to finish. Headquarters for the SOCIETY meetings was the Hotel Cleveland, and the Metal Exposition was held in the nearby Public Auditorium.

Some 1426 members and guests paid their registration fee; several hundred additional people attended one or more of the AWS sessions, having registered with one of the other Engineering Societies taking part in the Metal Congress.

The AWS meeting was formally launched on Monday, October 19th, with an Address by President Fred Plummer. This high-spot review of an interesting year of progress was published in the December issue of THE WELDING JOURNAL. Mr. Plummer's address was followed by presentation of the Lincoln Gold Medal Award, the RWMA Prize Paper Awards and the A. F. Davis Undergraduate Welding Awards. These too have been described in previous issues of THE WELDING JOURNAL. The Adams Lecture was presented, for the first time, by a Foreign Engineer, R. B. Shepheard

Some of the 350 members and their ladies who made the President's Reception a truly scintillating and enjoyable social event

Authors, Technical Sessions Chairmen and Supervisors attending Author's Breakfast on Monday, October 19th

This large crowd listening to the Adams Lecture was typical of the excellent attendance at the various Technical Sessions

One of the important events was the presentation of awards and prizes. Here President F. L. Plummer presents Honorary Member Certificate to H. Malcolm Priest

of the Shipbuilding Conference, London, England. Mr. Shepheard's lecture "Aspects of Welding Research in British Merchant Shipbuilding" is reproduced in this issue.

The 19 Technical Sessions, involving 60 technical papers, began on Monday afternoon and continued throughout the week, ending on Friday noon. These were supplemented by an educational lecture series by Dr. H. Udin of M.I.T. Practically every phase of welding was covered and, for the most part, the papers were extremely well received and represented another milestone of progress.

The serious business was enlivened by several social events, such as the President's Reception on Monday evening, October 19, attended by 350 members and their ladies, and the Annual Dinner on Thursday evening, sponsored by the Cleveland Section, and attended by some 400 merrymakers. Entertainment, food and music were outstanding at this banquet. The festivities also constituted the pleasant occasion of the awards covering the Miller Medal, the Adams Lecture and an Honorary Membership. These awards have been previously described.

Other events included special plant visits to the Euclid Road Machinery Co. and to the Cleveland Tank Plant of Cadillac Motor Car Division, GMC. Approximately 150 members took advantage of these tours.

Business events included authors' breakfasts each morning, Convention Committee meeting and luncheon, National Officers Dinner, Nominating Committee meeting, Membership Committee meeting, Manufacturers Committee meeting, WRC University Dinner and Conference, Annual Business meeting, Section and District meeting and Board meeting, in addition to several Technical Committee meetings.

The Ladies' Program included a Luncheon and fashion show on Monday; Luncheon and sightseeing trip on Tuesday; Luncheon and stage play Wednesday; Brunch, Card Party and Banquet on Thursday.

Special credit for the over-all success of this Annual Meeting is due to the members of the Cleveland Section. They were represented by a well-organized, smooth-running convention arrangements group that took all things in their stride and handled details for registration, membership work, sales of printed matter, technical sessions and the various social events.

In one convention week there was packed an educational, inspirational, friendship and good will enterprise that could not be equalled in any other way for the same expenditure of time and money.

Final Meeting of Board of Directors 1952–53 Year

The final 1952–53 Board of Directors meeting was held on Thursday, Oct. 22, 1953, at 9:00 A.M. in Parlors 34 and 36, Parlor Floor, Hotel Cleveland, Cleveland, Ohio, with the following present:

Members: F. L. Plummer, *Chairman*; J. H. Humberstone, J. H. Blankenbuehler, J. E. Dato, J. U. Durham, O. B. J. Fraser, R. S. Green, LaMotte Grover, D. B. Howard, T. B. Jefferson, C. H. Jennings, I. Morrison, I. O. Oehler, H. E. Rockefeller, M. S. Shane, J. R. Stitt, C. B. Voldrich and E. O. Williams.

Staff: J. G. Magrath, *Secretary*, and F. J. Mooney, *Assistant Secretary*.

Guests: H. O. Hill, Chairman, Constitution and By-Laws Committee; J. Lyell Wilson, Chairman, Technical Activities Committee; J. J. Chyle, 2nd Vice-President-Elect 1953–54; C. E. Jackson, District Director 1953–54; J. W. Mortimer, Director-at-Large 1953–54; A. E. Pearson, District Director 1953–54; C. P. Sander, Director-at-Large 1953–54; Hal Savage, District Director 1953–54; C. M. Styer, District Director 1953–54; R. L. Townsend, Director-at-Large 1953–54; and J. B. Welch, District Director 1953–54.

Secretary's Report

The Secretary distributed copies of his Annual Report for the 1952–53 year to each Board Member and advised that he would officially present the written report at the Annual Business Meeting following. Within the interim, it was presented for acceptance by the Board in Session.

Action: Upon motion, duly seconded, the Secretary's Report was accepted.

TAC Recommendations

Technical Activities Committee submitted recommendations covering the following items, details of which were submitted to all Board Members with Agenda for this meeting:

TAC-2: AWS Army Ordnance Advisory Committee.

TAC-3: Recommended practices for repair welding of cast-iron pipe, valves and fittings.

TAC-4: Tentative Specifications for chromium and chromium nickel steel welding rods and electrodes.

TAC-5: Tentative Specifications for copper and copper-alloy welding electrodes.

Action: Upon motion, duly seconded, the foregoing recommendations, as submitted with Agenda, were approved.

Appointment—Assistant to Technical Secretary

J. Lyell Wilson, Chairman of TAC, reported that after two unsuccessful trials which included the engagement of a person for the position of Assistant to the Technical Secretary, but who turned out unsatisfactory, those involved in the obtaining of someone to fill this position had concluded the task was made practically impossible by the nonavailability of engineering trained persons who would accept the position on the basis of the $5000 maximum salary previously approved by the Board of Directors. The Technical Activities Committee recommended that this salary bracket be raised to $6500, and that an attempt be again made to fill the position, also that the Secretary of the Society and the Chairman and the Secretary of the Technical Activities Committee be empowered to employ such assistant without further approval by the TAC. The foregoing was contained in the TAC recommendations attached to Agenda.

Action: Upon motion, duly seconded, the Technical Activities Committee's recommendation was approved.

Reserve Funds Committee Annual Report

J. Lyell Wilson, Chairman of the AWS Reserve Funds Committee, presented his Annual Report as shown as Exhibit A following the main report of the meeting.

Action: Upon motion, duly seconded, the Annual Report of the Reserve Funds Committee was accepted and recommendations contained therein were approved.

Revised AWS By-Laws

H. O. Hill, Chairman of the Constitution and By-Laws Committee, reviewed the order from the Board of Directors to the Constitution and By-Laws Committee to completely revise the Society's By-Laws in a manner which would include all existing rulings of the Board of Directors, all recent recommendations by the Board of Directors for changes in By-Laws, and a provision whereby it would only be necessary to send Letter-Ballots to the Membership for By-Law revisions in the instances where such By-Law revisions would affect the interest of the Membership. Mr. Hill reported that after a number of meetings of the Constitution and By-Laws Committee, one of which was in company with the AWS Executive Committee, he now submitted a complete set of revised By-Laws. Orally he briefed the Board Members on those changes which he considered vital and requiring their immediate interest, decision or comment. Items of major consequence were as follows:

In the revised By-Laws, as submitted, the Life Membership, granted to a President of the Society as an award for his serving as President, had been combined

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with Honorary Membership. There was disagreement regarding this inclusion on the part of a number of Board Members. In discussion it was agreed to change the revisions to accommodate the separation of Life Membership from the Honorary Membership classification.

There had been recommendations and Board action in regard to changing the name of the National Society's component, "Section" to the word, "Chapter." Mr. Hill stated that his Committee had given this change weighty consideration and that his Committee's opinion was that the change in name was of no consequence, but rather would only cause confusion over a period to time during the transition of acceptance of terminology as well as for the period during which existing AWS literature, rules, procedures, etc., contained the name "Section," whereas new issues and correspondence would be employing the word "Chapter." Further, it would be costly and wasteful to destroy all existing literature and impractical to reprint it for a change of no consequence. He further stated that in his survey of the major engineering societies, the greater number by far, employed the name "Section" for their territorial components rather than the name "Chapter." In discussion thereafter, and in the order of a vote taken, the previous action of the Board of Directors was rescinded, and the Constitution and By-Laws Committee's recommendation that the name "Section" be retained, was accepted.

The moot question as to whether or not a new Office of Assistant to District Director (the new revised By-Law name for the previously titled, "District Vice-President") was reviewed. By previous action, the Board of Directors had approved of the creation of this Office. The Constitution and By-Laws Committee could not see the need for its creation in that it was a dividing of responsibility, would unnecessarily add to the over-all weight of correspondence of the Society and, further, the projected reason for the creation would more aptly be satisfied by a later recommendation which was to be received from the Section Advisory Committee that additional Districts be created. Messrs. Morrison and Durham strongly advocated the creation of the new Office. Mr. Durham explained that his recommendation, comprised of the Offices of District Director and Assistant District Director being entitled to but one vote on the Board of Directors, either to serve as the other's alternate at Board meetings. There was considerable discussion as to possible advisability of such split-responsibility arrangement. Temporarily, the item was tabled.

Other items were reviewed in the order of recommendations by the By-Laws Committee, such as the optional provision for referring Membership applications to the Committee of Admissions; the appointment of the Chairman of the Section Advisory Committee to be the privilege of the President, such office not to be an encumbent holder of the Office of District Director; the appointment by the President of the Chairmen of the Reserve Funds Committee and the Awards Committee. These minor changes met with the approval of the Board at large.

The item of appointment of Assistant to the District Director was brought from the table and a vote taken. By far, the majority voted against the creation of the Office of Assistant District Director.

Mr. Hill reviewed the By-Law provision for the creation of Meritorious Certificate Awards and explained why he combined both certificate awards of this character at the National and the District-Section level in the same provision. In discussion, it was proposed that nominees for the Meritorious Certificate Awards, at the District-Section level, be recommended by a District Committee, comprising the District Director as Chairman and either the Chairman, or his appointee of each Section, as a Member. The Society's Secretary advised, at this time, that the entire Awards Committee pattern was being revised and that the new By-Laws would provide for an over-all policy-making Awards Committee at the national level and that the various specific awards would be administered by the Subcom-

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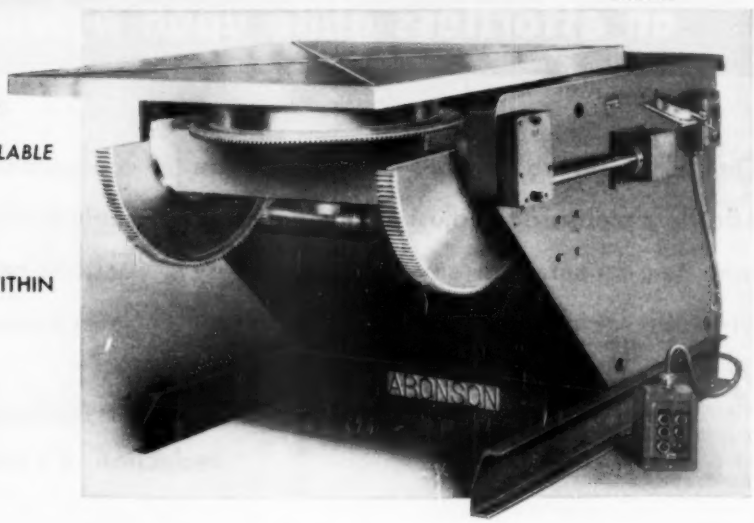

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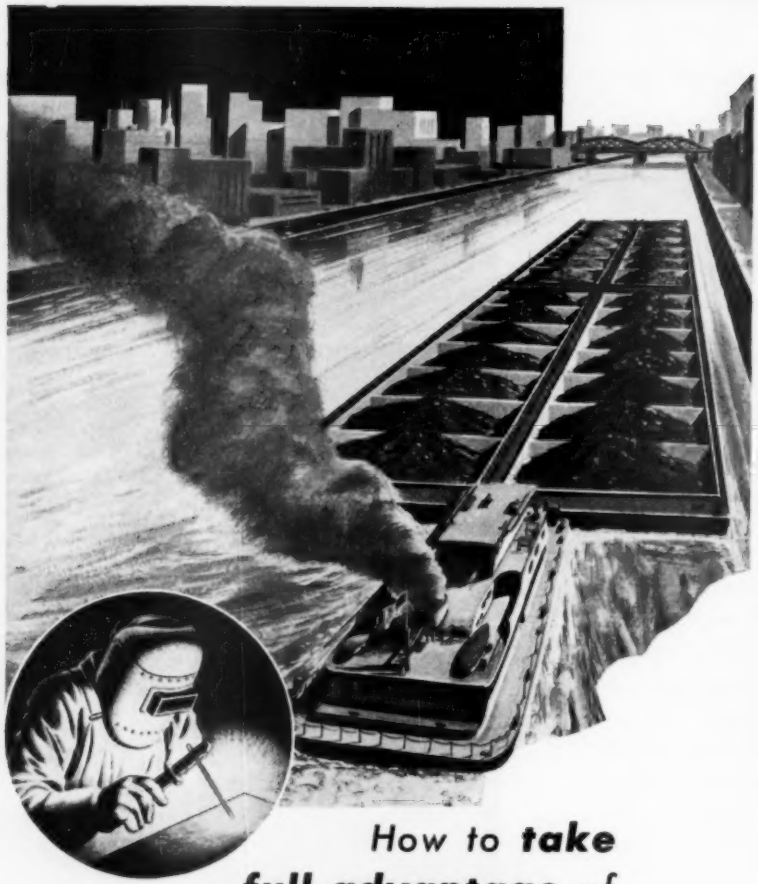

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mittees of the National Awards Committee. He stated that the Awards Committee, at the District-Section level, as recommended, could very well function under the provisions being proposed. It was decided to change the limit of six District-Section awards per year to one award per year for each District.

The Constitution and By-Laws Committee was commissioned to proceed with the final composition of By-Law text in the order as submitted by them and on the recommendations as given at this meeting by the Board Members. Such composition and inclusion hereby receiving the approval of the Board Members in the order of the action following:

Action: Upon motion, duly seconded, the By-Laws revisions, as submitted by the Constitution and By-Laws Committee, were approved, with the provision that major recommendations, in the order of the foregoing, as made by the Board of Directors and including the minor recommendations as recorded by Mr. Hill, Chairman of his Committee, were to be included in the final text. It was also recommended that these By-Laws be established effective as quickly as possible. It was further moved, duly seconded and approved, that the By-Laws Committee was to be commended for its excellent performance and work in the monumental task of revising the SOCIETY's By-Laws, as requested by the Board of Directors, and that particular commendation was hereby given to H. O. Hill as Chairman of his Committee.

Secretary's Notes: The Secretary observed that in order to effect the changeover from old By-Laws to the new, during the transition period, there would be, understandably so, considerable confusion, and that there would be considerable actions that would require the Secretary's immediate and unapproved action. In order to effectively terminate the fiscal year, there probably would be recommendations coming from the Secretary's Office to the Board of Directors which might affect some decisions made at this meeting. These could not be foreseen until such time as the problem arose and execution or satisfaction thereof was required. The Board of Directors, as voiced by the Chairman of the Board, expressed understanding of the situation and advised the Secretary to proceed in the best possible manner during the interim period of transition.

Recommendations of Section Advisory Committee-District Reapportionment

T. B. Jefferson, Chairman of the Section Advisory Committee, reported that his Committee, through correspondence and meeting, on the basis of assignment from the Board of Directors, arrived at a plan for District reapportionment which would result in increasing the number of Districts from the existing seven to a total of 11. The recommendation consists of

eleven Districts which are listed as follows: (1) The New England District, (2) The Middle Eastern District, (3) The North Central District, (4) The Southeast District, (5) The East Central District, (6) The Central District, (7) The West Central District, (8) The Mid-West District, (9) Southwest District, (10) The Western District and (11) The North West District.

He observed that this increase in number of Districts would increase the number of District Directors, and, therefore, would increase the number of Members of the Board of Directors by an additional four Members. (*Secretary's Note:* This number is still within the provisions allowed by the SOCIETY's Certificate of Incorporation.) He advised that there had been some discussion and reluctance on the part of some Districts inasmuch as they would be losing Membership as against others who would gain Membership thereby. He stated that his Committee had to be somewhat arbitrary and do the best job possible on the basis of geographical layout as well as ability, due to travel routes—rail and air—of District Directors, to cover the area and Sections within their Districts.

Action: Upon motion, duly seconded, the recommendations of the Section Advisory Committee, were approved, such to become effective, if possible, at the next election of District Officers.

Eric Seabloom Memorial Resolution

A Memorial Resolution was submitted by a Committee of two, T. B. Jefferson and William Pearson, as appointed by the Board of Directors, in recognition of the passing of Eric R. Seabloom, First Vice-President. At the request of the Chairman, the Secretary read the Memorial Resolution as submitted with Agenda as Attachment E. After the hearing thereof, recommendations were made for minor modifications which were felt to be more in keeping with the spirit of the Resolution and which amendments were accepted by T. B. Jefferson, present in meeting. The revised Memorial Resolution is included as Exhibit B (see p. 64).

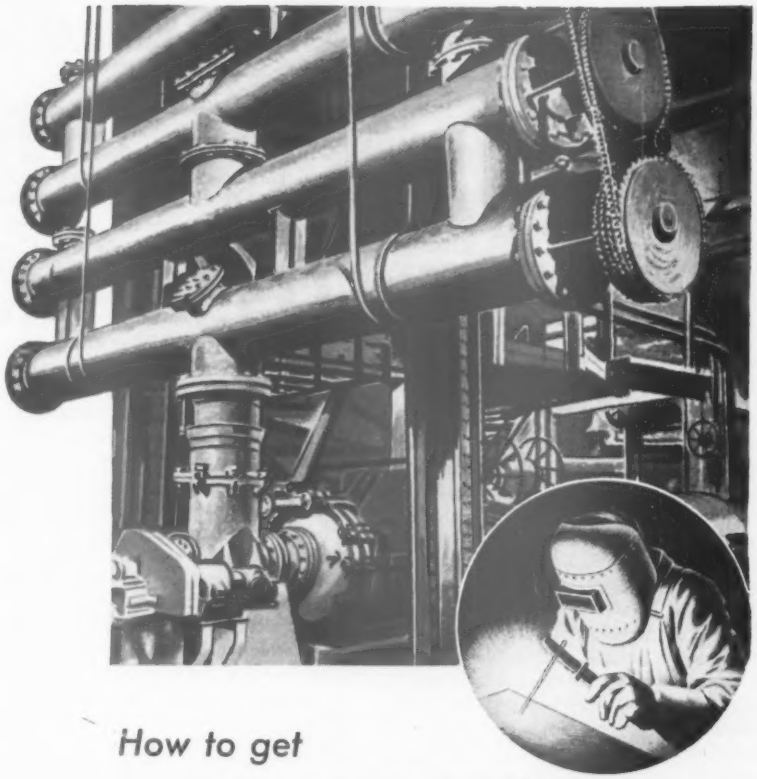
Action: Upon motion, duly seconded, the Eric R. Seabloom Memorial Resolution, as submitted in Attachment E, was approved.

EXHIBIT A

ANNUAL REPORT FOR 1952–53
AWS COMMITTEE ON RESERVE FUNDS

The AWS Committee on Reserve Funds conducted its business during the past year entirely by correspondence, except that the Chairman, following routine procedure, accompanied and checked with the Assistant Treasurer, F. J. Mooney, in depositing interest coupons as they matured.

The Committee authorized the Assistant Treasurer, F. J. Mooney, to purchase and add to the Reserve Fund portfolio the following industrial bonds which are



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When you weld clad materials you are welding dissimilar metals. The weld metal will be a combination of the two base materials plus the filler metal of the electrode.

Proper electrode selection is an essential step in developing the required corrosion resistance in a weld. Just as important as the selection of electrodes in clad welding are correctly designed joints and proper heat treatments.

Arcos long experience in welding stainless and the clad materials can guide you in the selection of the proper electrode and welding procedure necessary for successful fabrication. Take advantage of the rigidly controlled qualities of Arcos electrodes to get consistently sound welds at a low overall cost.

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within the scope of investments authorized by the Board of Directors:

Quantity	*Security*	*Total Cost**
$2000	Michigan Consolidated Gas. 3½–69—March & Sept.	$2063.56
$4000	Sinclair Oil Corp. 3¼—83—Jan. & July 15th	$3867.50
$1000	Sinclair Oil Corp. 3¼—83—Jan. & July 15th	$ 968.13

* Total cost includes $22.50 commissions and $49.19 the latter being recoverable at the time the first interest coupons mature.

The foregoing purchases were made as of Oct. 8, 1953, and are therefore additional to the items listed in the following Statement of Reserve Funds as of Aug. 31, 1953 and their total cost of $6899.19 (gross) is a deduction from the Cash on Deposit in Emigrant Industrial Savings Bank of $7788.84 shown in the statement.

The new purchases are registered in the name of the AMERICAN WELDING SOCIETY. During my visits to the Safety Deposit Box it has been observed that, with few exceptions, the securities held in this portfolio are "Bearer Bonds." It is therefore strongly recommended as good business policy that consideration be given to the matter of having all bearer bonds in the portfolio changed to registered bonds—registered in the name of the AMERICAN WELDING SOCIETY.

Respectfully submitted,

J. LYELL WILSON, *Chairman*
AWS Reserve Funds Committee

EXHIBIT B

MEMORIAL RESOLUTION

ERIC R. SEABLOOM

Resolved, that the Board of Directors of the AMERICAN WELDING SOCIETY regard the death of Eric R. Seabloom as a great loss to both the SOCIETY and the welding industry. Mr. Seabloom was a member of the SOCIETY for many years and was widely known and prominent in its affairs. He is remembered with affection and admiration for his cheerful personality and for the willingness with which he gave his time, thereby contributing immeasurably to the progress of welding by service on many of the committees of the SOCIETY. In addition, Mr. Seabloom contributed to the marked progress of the SOCIETY in which he held the offices of Second and First Vice-President and to the Chicago Section where he had held successive office through the Chairmanship.

Be it further Resolved that the AMERICAN WELDING SOCIETY, by action of its Board of Directors, express its appreciation of Eric R. Seabloom's services by spreading this Resolution in the records of the SOCIETY and that the Secretary be instructed to transmit a copy of this Resolution to Mrs. E. R. Seabloom; to his company; and the Chicago Section.

Respectfully Submitted,
(Signed) T. B. JEFFERSON
(Signed) W. C. PEARSON

First Meeting of Board of Directors 1953–54 Year

The first meeting of the Board of Directors for the year 1953–54 was held on Thursday, Oct. 22, 1953, at 3:00 P.M. in Parlors 34 and 36, Parlor Floor, Hotel Cleveland, Cleveland, Ohio, with the following in attendance:

Members: F. L. Plummer, *Chairman*, J. H. Humberstone, J. J. Chyle, J. H. Blankenbuehler, J. E. Dato, O. B. J. Fraser, R. S. Green, D. B. Howard, C. E. Jackson, C. H. Jennings, I. Morrison, J. W. Mortimer, I. A. Oehler, A. E. Pearson, C. P. Sander, Hal Savage, M. S. Shane, C. M. Styer, R. L. Townsend, Jerome Welch and E. O. Williams.

Staff: J. G. Magrath, *Secretary*, and F. J. Mooney, *Assistant Treasurer*.

Guests: J. U. Durham, District Vice-President 1952–53; LaMotte Grover, Director-at-Large 1952–53; T. B. Jefferson, District Vice-President 1952–53; H. E. Rockefeller, Director-at-Large 1952–53; J. R. Stitt, Director-at-Large 1952–53; C. B. Voldrich, Director-at-Large 1952–53.

Appointment of Officers

The Chairman called upon the Board for the appointment of a Secretary and an Assistant Secretary and Assistant Treasurer for the 1953–54 fiscal year.

Action: Upon motion, duly seconded, J. G. Magrath was appointed Secretary and F. J. Mooney was appointed Assistant Secretary and Assistant Treasurer for the 1953–54 fiscal year.

Designation for Official Signatures

The Chairman recommended, in the order of the previous custom, that the SOCIETY's President and the SOCIETY's Treasurer, and in the absence of either, the Assistant Treasurer be authorized to sign

AMERICAN WELDING SOCIETY STATEMENT OF RESERVE FUNDS, AUG. 31, 1953

	Cost	*Market value*	*Annual interest received*	*Amortized cost*
Reserve Funds Committee Account:				
$ 1,500—Par U. S. War Savings Bonds, series F	$ 1,110.00	$ 1,443.00	$	$ 1,443.00
$ 7,000—Par U. S. Treasury Bonds, 2½% due 12/15/63–68	7,000.00	6,554.10	175.00	7,000.00
$10,000—Par U. S. Treasury Bonds, 2½% due 12/15/69–64	10,000.00	9,317.00	250.00	10,000.00
$ 8,000—Par U. S. Treasury Bonds, 2¼% due 12/15/62–59	8,006.50	7,541.60	180.00	8,003.65
$ 2,000—Par U. S. Treasury Bonds, 2¼% due 12/15/62–59	2,057.13	1,885.40	45.00	2,034.96
$15,000—Par U. S. Treasury Bonds, 2½% due 3/15/65–70	15,000.00	13,966.50	375.00	15,000.00
$10,000—Par U. S. Treasury Bonds, 2½% due 3/15/65–70	10,031.26	9,311.00	250.00	10,018.07
$ 7,500—Par U. S. Treasury Bonds, 2½% due 3/15/71–66	7,500.00	6,926.25	187.50	7,500.00
$10,000—Par U. S. Treasury Bonds, 2½% due 6/15/72–67	10,000.00	9,223.00	250.00	10,000.00
$ 7,500—Par U. S. Treasury Bonds, 2½% due 12/15/67–72	7,590.56	6,917.25	187.50	7,558.94
$ 6,000—Par U. S. Treasury Bonds, 2½% due 12/15/67–72	6,100.88	5,533.80	150.00	6,082.56
$ 7,000—Par U. S. Treasury Bonds, 2½% due 12/15/67–72	7,194.69	6,456.10	175.00	7,137.60
$ 8,000—Par U. S. Treasury Bonds, 2½% due 12/15/67–72	8,224.00	7,378.40	200.00	8,158.24
$ 2,000—Par U. S. Treasury Bonds, 2¼% due 12/15/62–59	2,058.38	1,885.40	45.00	2,047.00
$ 3,000—Par Michigan Consolidated Gas Co., 3½% due 3/1/1969	3,135.75	3,041.25	105.00	3,108.35
$ 5,000—Par American Telephone & Telegraph, 3¾% due 3/19/1963	5,900.00	5,712.50	168.75	5,777.40
	$110,909.15	$103,092.55	$2743.75	$110,869.77
Cash on Deposit in Emigrant Industrial Savings Bank				7,788.84
Due from SOCIETY—1% of Gross Income				3,486.37
TOTAL RESERVE FUNDS COMMITTEE ACCOUNT				$122,144.98

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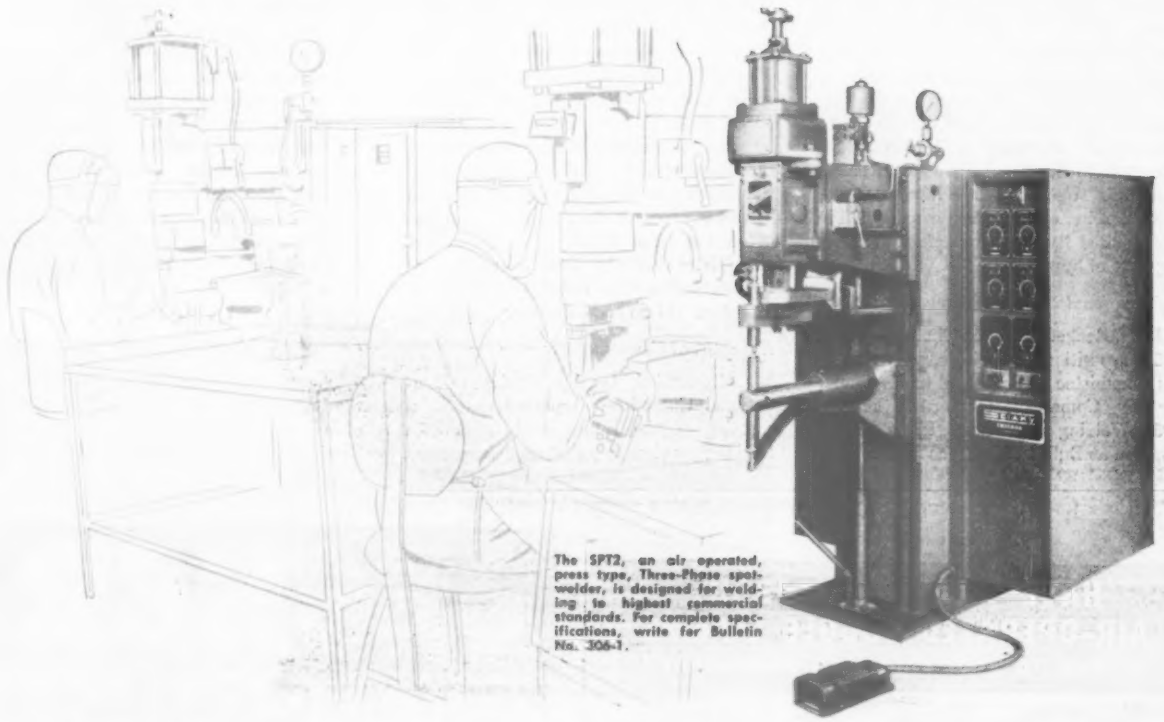

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Not only did the strength of spotwelded assembly exceed requirements, but Sciaky Three-Phase operation eliminated need for special metal finishing.

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checks and other documents in behalf of the SOCIETY during the 1953–54 fiscal year.

Action: Upon motion, duly seconded, the Chairman's recommendations were approved.

Executive Committee Authority

In the order of past custom, the Chairman recommended that the Executive Committee be vested with authority to transact the business of the SOCIETY's Board of Directors, in-between Board Meetings. The Secretary advised that in approving the revised By-Laws, the previous 1952–53 Board, at its immediate previous meeting, had granted approval *per se*, but due to the required transition period of procedure conversion from previous to revised by-law administration, it was advisable that this Board at this session give a confirming vote on the extension of the authority of the Board of Directors to the Executive Committee.

Action: Upon motion, duly seconded, the extension of authority, as provided in the Revised By-Laws, was given confirming vote of approval.

Informational; 1954 Welding Exposition

H. E. Rockefeller, Vice-Chairman of the 1954 Exposition Committee, advised that his Committee had reported to the Manufacturers Committee in regard to the May 1954 Welding and Allied Industry Exposition at Buffalo, N. Y., as follows:

Exhibitor space reservation forms will be mailed about November 1st. Based upon sale of 13,000 sq ft, budget indicates estimated expense of $24,000 and income of $38,000; a gross surplus of $14,000 prior to deduction of National Spring Meeting and Convention expense. He advised that as of May 1, 1954, labor negotiations may be under way in Buffalo, but the verbal assurances received by the Exposition Manager from both contractors and union organization in Buffalo influenced the Exposition and Manufacturers Committees favorably, and they believed that no difficulty would be experienced. The Manufacturers Committee recommended that the Exposition be limited to three days and to hours as follows: May 5th, 6th and 7th; Wednesday and Thursday—10:00 A.M. to 10:00 P.M., and Friday—10:00 A.M. to 6:00 P.M. The Manufacturers Committee at the suggestion of the SOCIETY Secretary are giving some thought to an Exhibitors' Reception on Tuesday evening, May 4th, but no decision has been made. The Exposition Committee believes that a number of manufacturers who failed to exhibit at Houston, will do so at Buffalo.

Educational Committee Program

J. Heuschkel, Chairman of the Educational Committee, reported that at a meeting of the Educational Committee held the previous day that group expressed appreciation to the SOCIETY for providing in the Budget for this year $1000 for Educational Committee activities. That group recommended to the Board that it be allowed to solicit funds from industry to an extent not to exceed $5000 and that if so approved, then the Educational Committee would conduct the solicitation program. The Board of Directors, before granting permission to the Educational Committee to solicit industry for funds, voted that the Educational Committee through the establishment of an Executive Committee of the Educational Committee, should meet and develop a formal program for carrying out its proposed activities. The Board suggested that the Executive Committee of the Educational Committee call such a meeting and expenses involved for this meeting could be charged against the $1000 already allowed this Committee. If, however, as a result of this meeting, a satisfactory program could not be developed, then the SOCIETY would underwrite expenses resulting from this meeting. The SOCIETY's Secretary was instructed to send a letter to Mr. Heuschkel outlining action taken.

Permanent Membership Award Recognition

The Secretary requested approval of the Board of Directors for the presentation of a special certificate to the Houston Section for its exceptional accomplishment

HAVE YOU HEARD ABOUT AIR-OPERATED TOGGLE CLAMPS to step up your clamping operations?

Knu-Vise (AODT-400) Double-toggle Clamp to clamp "around the corner"

Knu-Vise (AO-400) Toggle Clamp for conventional clamping.

In cases where the cylinder interferes with conventional clamping, the Double-Toggle Clamp shown at the top serves such difficult mounting situations as illustrated in the superimposed line drawing.

Available in 3 series

- For 200 lbs. clamping force Models AO-200 and AODT-200
- For 400 lbs. clamping force Models AO-400 and AODT-400 (illustrated)
- For 1200 lbs. clamping force Models AO-1200 and AODT-1200

Cylinders can be easily rotated to suit air supply from either left or right side.

Send for complete information.

KNU-VISE PRODUCTS LAPEER MFG. CO.
3066 DAVISON ROAD • LAPEER, MICHIGAN

BECKER
KEEN-ARC CARBONS

FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

BECKER BROTHERS CARBON CO.
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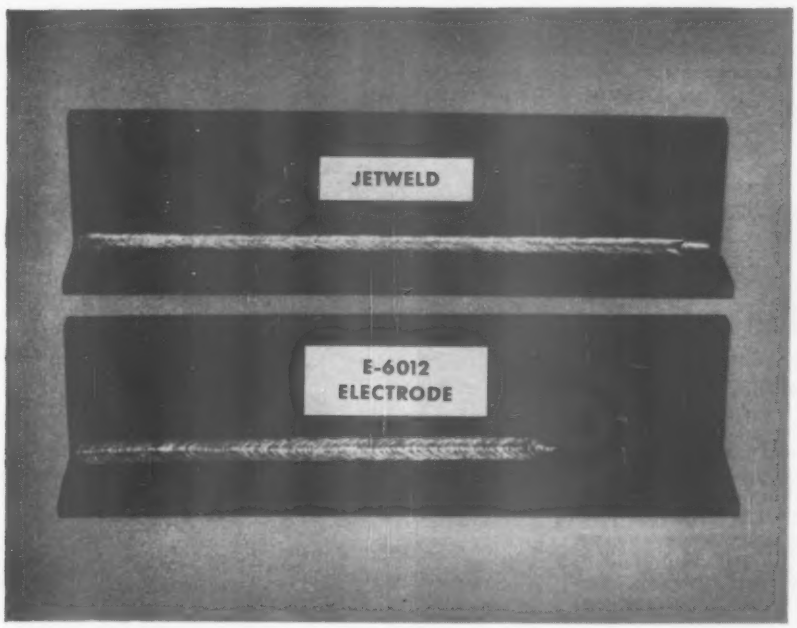
IT TAKES SPEED

to *really* cut welding costs

HERE ARE THE FACTS! 86¢ out of every welding dollar goes for labor and overhead. Obviously, the most effective way to cut welding costs is to boost welding speeds. This is exactly what you accomplish by using the *right* Lincoln electrode for your welding job. Each Lincoln electrode is designed to do a *specific type of job*... do it faster because Lincoln has higher *useable* melt-off rates to give more footage than possible with other makes. This actual test proves the *extra speed* you get with Lincoln electrodes.

TEST OBJECTIVE: To compare the welding speed of Jetweld with the best other make E-6012 electrode in horizontal fillets.



	LINCOLN JETWELD	THE FASTEST E-6012 ELECTRODE
PLATE SIZE	3/8"	3/8"
FILLET SIZE GAUGE	1/4"	1/4"
ELECTRODE SIZE	5/16"	1/4"
CURRENT AMPS.	275 AC	350 AC
ARC SPEED INCHES PER MINUTE	15.0	11.0
DEPOSITION RATE—POUNDS PER MINUTE	.140	.135

LINCOLN JETWELD IS 36% *FASTER* IN THIS SPECIFIC APPLICATION

INVESTIGATE WHICH COST-CUTTING COMBINATION OF THESE LINCOLN ELECTRODES IS BEST FOR YOU

- For flat and horizontal fillets—high-speed, self-cleaning, submerged-arc-like appearance . . . *JETWELD.*
- For welds having poor fit-up. All positions—E-6012 . . . *FLEETWELD 7.*
- Soft arc action, easy-cleaning welds. All positions —E-6013 . . . *FLEETWELD 47.*
- High-speed production welding of lap and fillet welds. E-6012 . . . *FLEETWELD 72.*
- For deep penetration, structural and pipe welding butt and fillet welds in flat, vertical, and overhead positions . . . *FLEETWELD 5.*

GET THE FACTS. Speeds and procedures for mild steel electrodes are in Bulletin 462, available by writing on your letterhead.

THE LINCOLN ELECTRIC COMPANY
DEPT. 1913, CLEVELAND 17, OHIO
THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT

of winning the Neitzel National Membership Award for the third consecutive year and for such certificate to become the permanent possession of the Houston Section. It was observed that perhaps a gavel or some other token of appreciation would be desired in preference to a certificate. The Board so authorized the presentation of an award to the Houston Section and the type of award be in the order agreed upon by the Houston Section and the SOCIETY's Secretary.

Membership Advertising

J. R. Stitt, Chairman of the 1953–54 National Membership Committee, acting for his Committee, recommended the reinstatement of the 1952–53 Membership Advertising program, in the following order: Twelve full-page ads in THE WELDING JOURNAL—one each month; six full-page ads in *The Welding Engineer*—on alternate months commencing with the December 1953 issue; six full-page ads in *Industry and Welding* on alternate months commencing with the December 1953 issue. He further recommended that the Membership Committee be responsible for effectuating and supervising the program.

Action: Upon motion, duly seconded, the Board of Directors authorized the SOCIETY Secretary to provide a sum, not to exceed $5000 during the 1953–54 fiscal year, for membership advertising; such amount to be taken from the SOCIETY's operating funds, and all advertising production and space costs to be charged against the authorized sum. The Membership Committee was instructed to submit prior to placement, all advertising copy to the SOCIETY Secretary for review and/or editing in accordance with SOCIETY policy.

National Manual

C. H. Jennings requested information on what progress was being made for providing the SOCIETY's National elected Officers, including Members of the Board of Directors, with instructions as to their respective duties, in clarification of and supplemental to the SOCIETY's By-Laws. Chairman Plummer reported that the SOCIETY Secretary had submitted a rough draft to him which also included recommendations to both National and District Nominating Committees for guidance in selecting candidates for national offices. He believed the draft submitted was satisfactory and was hereby giving his approval for its release in the form of a "national manual." The Secretary advised that he would proceed to issue as soon as he received the text of the final revised By-Laws from the Constitution and By-Laws Committee, and the required portions thereof could be incorporated in the National Manual. He advised that the first release would probably be in mimeographed form, to be followed later in photo-offset.

Appreciation to the Cleveland Section

The Board of Directors requested that their unanimous vote of appreciation be extended to the Cleveland Section for the excellent arrangements program, and its execution, during the week of the SOCIETY's 1953 National Fall Technical and Annual Meeting in Cleveland.

OBITUARY

Thomas S. Gaylord

Thomas S. Gaylord of Rochester, N. Y., died suddenly October 31st in Marietta, Ga., on his way to Florida. He was 66.

Mr. Gaylord was the first Chairman of the Rochester Section AWS during 1938. He was employed by the Eastman Kodak Co., at Kodak Park for 40 years. Starting as a machinist in 1911, he later became foreman and then superintendent of the Metal

Shop. For five years, prior to his retirement in 1951, he served as welding consultant. He was very much interested in welding and took an active part in the Rochester Section. In 1938 he received a high award for a paper submitted to the Lincoln Welding Foundation. He was a past president of the Kodak Park Foreman's Club, a member of the ASM and the Kodak Pioneers' Club. He leaves his wife Elizabeth; two sons Elsworth and Robert; a sister Mrs. Sarah VanWickler and four grandchildren.

OF COURSE. . .
the nickel in manganese-nickel steel helps produce far better results!
THAT'S WHY
GYRATORY CRUSHERS
REBUILT WITH
MANGANAL
U.S. Patents 1,876,738 - 1,947,167 - 2,021,945
11%-13½% MANGANESE-NICKEL STEEL
ROUND APPLICATOR BARS
Usually outlast new ones!
FREE Send for literature on speedy and economical repair of worn equipment.
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FOR EVERY INERT GAS WELDING JOB

As every welder knows, you can't use the same electrode on every job. For best performance and longest electrode life, you must select the right rod for every particular purpose.

This is why Sylvania offers 3 *different* tungsten electrodes to meet the full range of requirements of any inert gas arc welding work.

Sylvania . . . a pioneer in tungsten

Sylvania is a pioneer in the development of tungsten in many forms. As a result, our engineers and metallurgists have provided the precise type of tungsten rod for every need. Sylvania's research and advanced techniques in manufacture and quality control . . . from ore to finished product . . . assure minute-saving operation and dollar-saving dependability.

Either Sylvania Puretung, Thoriated Tungsten or Zirtung Electrodes will answer any inert gas welding problem you have. So, order the types you require from your nearest Sylvania Welding Distributor today, or write to: Sylvania Electric Products Inc., Dept. 4T-4601, 1740 Broadway, New York 19, N. Y.

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*AMERICAN WELDING SOCIETY MEMBERSHIP SEPTEMBER 1, 1953 1412 NEW MEMBERS GAINED IN 1 YEAR

support A.W.S. activities

Since 1919, the American Welding Society has exerted a constant influence for the betterment of welding processes through research and exchanges of experience within its membership. Many of the 9349 men in A.W.S. are leaders in their respective industries today because of training and encouragement they have received from other "Men of Welding" in the Society.

A.W.S. builds "Men of Welding"

YOUR COMPANY CAN PARTICIPATE AND BENEFIT THROUGH A SUSTAINING OR SUPPORTING MEMBERSHIP. GET THE FACTS ABOUT A.W.S.

There are 66 active local sections of A.W.S. covering almost every part of the United States. They hold monthly technical meetings and plant visitations. They bring together the best welding minds of the nation and present accurate information on Welding design, fabrication and maintenance. You will profit from A.W.S. membership.

AMERICAN WELDING SOCIETY
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Please send me more information on advantages of membership in the American Welding Society

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Title .....

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City .....

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No. 2

*MEN OF WELDING" ADVANCE IN THEIR PROFESSION THROUGH TECHNICAL MEETINGS AND GROUP DISCUSSIONS ON WELDING METHODS AND PRACTICES.

American Welding Society

A POWERFUL FORCE IN WELDING PROGRESS SINCE 1919

33 WEST 39TH ST. • NEW YORK 18, N. Y.

NEW LITERATURE

Atomic Energy Reports

In an effort to help industry judge its interest in nonsecret reports on technological developments in the atomic energy program, a new bibliography series has been compiled by the AEC Industrial Information Branch.

Copies are available on request from the Industrial Information Branch USAEC, Washington 25, D. C. Announcements of AEC technical reports of interest to industry available in the future will appear in a special section of Nuclear Science Abstracts. NSA is issued twice monthly by the AEC and is available on a subscription basis at six dollars a year from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

Pipe Data Card

A new data card, designed to be of assistance to those involved in the selection, application and installation of carbon, alloy and stainless steel pipe, has been issued by the Tubular Products Division of the Babcock & Wilcox Co.

Known as TDC 138 A, the data card contains information on dimensions, weights, specifications, grades and analyses of seamless and welded carbon, alloy and stainless steel pipe. It presents pertinent data on six pipe-size schedules and complete reference data to steels covered by ASTM and ASME piping specifications.

Copies of this helpful data card are available free upon request to the sales offices of the Division at Beaver Falls, Pa.

The Case of the Ailing Weldollar

"The Case of the Ailing Weldollar" is the title of a new booklet available from the Lincoln Electric Co. of Cleveland, Ohio. It presents an analysis of the basic causes of high costs and suggests a plan for reducing these costs. According to analysis, labor and overhead are responsible for 87.85% of the cost of welding. The cure for this high cost is high usable welding currents, faster welding speeds and less machine downtime. How these can be achieved is presented briefly and with clear graphic explanation in the pages of the booklet. A copy is available by writing to A. F. Davis, the Lincoln Electric Co., Cleveland 17, Ohio.

Welding Engineering

Welding Engineering, by Boniface E. Rossi, Executive Secretary of the Pressure Vessel Research Committee of the Welding Research Council; Special Lecturer in Welding at the Stevens Institute. Price $8.00. 786 pp., including a comprehensive Index of 20 pages. Published by McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y.

Here is a volume that presents an up-to-date, crisply written, simplified, properly coordinated and readily understandable account of the science of welding.

The book familiarizes the student or beginner with fundamental facts concerning welding; gives those in the welding field a wider understanding of the process; and provides a useful source of reference for the draftsman, designer, engineer, researcher, executive, and anyone else seeking information on welding and its applications. Treatment is technical and practical.

Section One covers various welding processes such as forge, resistance, thermit, gas, pressure gas, arc, submerged arc, inert-gas-shielded arc, atomic hydrogen, stud, induction, flow and cold welding; also soldering, brazing, surfacing, metallizing, oxygen and arc cutting of metals, and safe practices, and health precautions.

Section Two deals with metals, their metallurgy and weldability. Section Three presents and discusses pertinent design and fabrication considerations such as welded design and its field of application; types of joints, welds and stress distribution; layer sequences, deposition rates, and welding costs; expansion, contraction and residual stresses in welding structures; welding jigs; and standard symbols adopted by the AMERICAN WELDING SOCIETY and their use.

Section Four treats the testing and inspection of welds. These five extremely useful and important appendices are included: welding terms and their definitions; selected bibliography; visual aids; questions and problems; and engineering data and talks.

Special Features

Text material is arranged in logical and practical sequence and presentation is based on the author's 13 years' experience teaching the subject at the college, trade school and industrial training level.

Recent developments in the field are covered, including several subdivisions of inert-gas-shielded arc welding and submerged arc welding, pressure gas welding, stud welding, cold welding, induction welding and flow welding.

This work includes the following topics which, in most cases, have never before been treated in a work of this kind: cold welding; certain phases of submerged arc welding, such as multiple electrode submerged arc welding; certain phases of inert-gas-metal arc welding with consumable electrode, such as semiautomatic process; certain phases of metal-arc welding, such as contact-arc welding and multiple-arc welding.

Material in this text has been tried in lecture form during the past five years by the author in his "Welding" course at the Industries Training School, Stevens Institute of Technology.

Welding Engineering is an easy-to-read book that should be useful both as a textbook and as a reference book for draftsmen, designers and engineers.

Eutectic Publishes Detailed Report

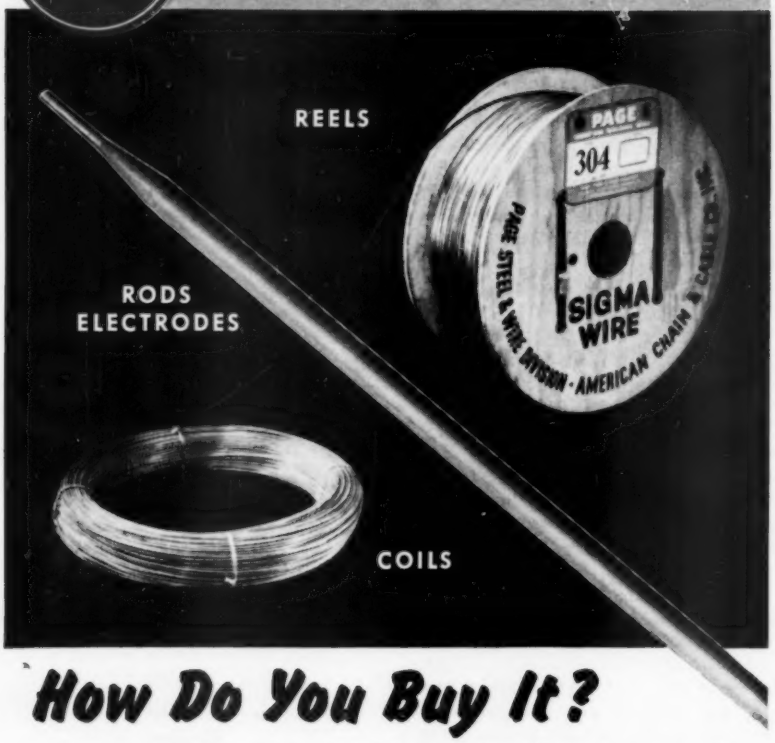
A 16-page brochure has just been released by the Eutectic Welding Alloys Corp., Flushing, N. Y., which describes in detail the history, products, manufacturing equipment and procedures together with the research projects and discoveries of the organization. This brochure is available free of charge from the Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y.

WRC Bulletin No. 16

The Welding Research Council has just issued its Bulletin No. 16 of its regular Bulletin Series. This Bulletin contains two reports: (1) "The Third Technical Progress Report of the Ship Structure Committee" and (2) a paper on "Research Under the Ship Structure Committee" presented before the Naval Architects, together with complete discussion. Together they summarize several years of recent progress made by the Ship Structure Committee in their research program which amounts to well over $300,000 a year.

Copies of this Bulletin may be ordered from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Price $2.00.

ACCO products for Stainless Steel WELDING



How Do You Buy It?

• No matter how you buy stainless steel welding wire—on reels, in coils, or packages of rods or electrodes—PAGE can supply you in a variety of analyses.

AC-DC Electrodes—Gas Welding Rods Stable burning even at lower heats. Slag is clean and easily removed. Coating resists cracking right down to short stubs. Your choice from a complete line for every type of stainless welding.

for Inert Gas Welding

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PAGE stainless in wire diameters from 1/32″ to 5/16″, plain or copper coated. In layer-wound coils, 22″ or 24″ mill coils, or 200-lb. returnable steel reels.

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TRADE MARK

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

PAGE Welding Electrodes Rods Wire

Fluxes

Krembs and Co. have issued a new bulletin and price list on their various fluxes. Twenty-six different Fluxine Fluxes are described—each for their particular use in welding steel, aluminum, stainless steel, etc. Included is the new 28H Fluxine in powdered form for gas, hydrogen, argon or heliarc welding of stainless steel and Inconel. Fluxine No. 47 is used for silver soldering steel, stainless steel, supermanganese bronze, copper and brass, as well as aluminum bronzes and beryllium copper. There are also data on their "Kop-R-Arc" coated welding electrodes for welding copper and all copper alloys.

A copy of this circular may be obtained by writing to Krembs & Co., 669 W. Ohio St., Chicago 10, Ill.

Protective Equipment

Chicago Eye Shield Co., 2300 Warren Blvd., Chicago 12, Ill., has just announced its new 64-page Catalog No. 27 showing a wide variety of head and eye protective equipment for industrial use.

Designed primarily for the man in charge of safety in foundries, factories, machine shops, mines, chemical plants, welding and grinding departments, the book contains hundreds of illustrations covering the many types and sizes of CESCO safety equipment.

Contents include safety glasses, goggles for welders and chippers, welding helmets, face shields, respirators, masks, hoods, aprons, sleeves and grinder guards. Copies may be obtained by written request on your company letterhead addressed to Chicago Eye Shield Co., 2300 Warren Blvd., Chicago 12, Ill.

New Welding Booklet

A 32-page "DirectoRod Guide" has been published by the Eutectic Welding Alloys Corp., 40-40 172 St., Flushing, N. Y. This comprehensive booklet gives recommendations for over 300 types of metal joining operations. There are over 40 illustrations of practical applications taken from case history files and there are 12 pages of easily followed charts.

The booklet is divided into sections, each dealing with a specific base metal. At the end of each section is a chart listing the electrodes, alloys and fluxes which may be used on the various types of base metal.

In the cast-iron section, for example, short illustrated case histories give examples of production, maintenance and repair welding with the type of alloy recommended for the particular operation. The section ends with a chart detailing specific applications in the first column. The following columns specify the arc electrodes, torch EutecRods and the fluxes recommended for maximum efficiency.

MADE BY SPECIALISTS -in Stainless Steels Monel Nickel
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FLOWLINE
.120" WALL
304
The FLOWLINE Tee
TRADE MARK
FLOWLINE Fittings are made by specialists whose entire efforts are devoted to making corrosion-resistant fittings. The unique features of these fittings are the result of our exclusive method of cold-forming and annealing, which puts them in the best condition for corrosion service. With FLOWLINE fittings, users of corrosion piping can obtain the full economies and efficiencies of butt-welded construction.
The tee shown has typical FLOWLINE features. It is stronger than the pipe with which it is used, is scientifically shaped, with round ends accurately machine tool cut and finished for easy fitting to pipe. Its large throat radii and smooth inner contours reduce pressure loss, minimize flow resistance, corrosion, erosion, and product accumulation.
FLOWLINE Welding Fittings—ells, tees, reducers, stub ends, and caps — are made and normally stocked at strategic points in Schedules 10, 40, and 80—(Schedule 5 also available) —sizes ½" through 12"—in stainless types 304, 316, 347; Monel and Nickel. They are annealed, cleaned bright—stainless fittings are passivated—and marked with type of metal, test number, size, schedule, and wall thickness.
WELDING FITTINGS CORP.
NEW CASTLE, PENNSYLVANIA
World's Largest Manufacturer of Stainless Welding Fittings

NEWS OF THE INDUSTRY

Welding Engineer

Examinations have been announced by the United States Civil Service Commission for filling positions of Welding Engineer, paying salaries from $3410 to $10,800 a year, in the Department of the Navy and in other Federal agencies in Washington, D. C., and vicinity.

To qualify for these positions, applicants must show appropriate education or experience in the field of work for which application is made; no written test will be given. Full details concerning the requirements to be met are given in Civil Service Examination Announcement No. 386.

Applications will be accepted until further notice and must be filed with the Executive Secretary, Board of U. S. Civil Service Examiners, Room 1109, Main Navy Bldg., Department of the Navy, Washington 25, D. C.

Further information on examinations may be obtained from most post offices or from the U. S. Civil Service Commission, Washington 25, D. C.

ASME Officers

The election of Lewis K. Sillcox, honorary vice-chairman of the board of the New York Air Brake Co., as president of the American Society of Mechanical Engineers for 1954, was announced on November 30th at the society's 74th annual meeting in the Statler Hotel, New York. The election of five regional vice-presidents and two directors-at-large was also announced. The new president succeeds Frederick S. Blackall, Jr., who is also president and treasurer of the Taft-Peirce Manufacturing Co. of Woonsocket, R. I.

The regional vice-presidents elected are Willis F. Thompson, vice-president, Westcott & Mapes, New Haven, Conn.; Prof. William G. McLean, head of the Department of Mechanics, Lafayette College, Easton, Pa.; Thompson Chandler, chemical engineer with the Carbide & Carbon Chemical Corp., South Charleston, W. Va.; Vernon A. Peterson, district manager for the Elliott Co., Los Angeles, Calif.; and Prof. Clifford H. Shumaker, director of the Institute of Management, Southern Methodist University, Dallas, Tex.

Elected directors-at-large are Frank L. Bradley, plant engineer, Forstmann Woolen Co., Passaic, N. J., and Robert B. Lea, coordinator of exports, the Sperry Corp., New York.

Engineering Awards

Dimitri Soussloff, Associate Director of Research for the Universal Winding Co. of Providence, R. I., manufacturers of textile machinery, received First Award in the recent national Award Program for welded machine designs sponsored by the James F. Lincoln Arc Welding Foundation of Cleveland, Ohio. Soussloff received $2981, the First Award, for his description of a yarn twisting machine, parts of which were redesigned for welded construction. The new design, it is estimated by Soussloff, will save the company a total of $100,000 a year, and in addition to being less expensive, the machine has greater adaptability.

The award was one of 77 made by the Lincoln Foundation to engineers and designers in all parts of the country, in its $30,000 Mechanical Design Award Program. Awards were made for descriptions of the design and fabrication of welded steel machines and components. The Program was sponsored, according to Dr. E. E. Dreese, Chairman of the Foundation, to "encourage industrial and economic progress through modernizing machine design for arc-welded steel fabrication. The designs submitted, such as Mr. Soussloffs, prove that industry, by using arc welding to its full advantage, could save millions of dollars annually and at the same time improve its products."

The Second Award of $2682 was given to David W. Kinney, Chief Engineer for the Pattin Manufacturing Co. of Marietta, Ohio. He described a special machine which was made to mechanize an unsafe and expensive hand-grinding operation on wedges used in bolting mine roofs. Arc welding made possible the fabrication of the machine by the company itself in 14 weeks and reduced the cost to 25% of the original estimate. It was paid for in savings on the job in less than six months.

Robert J. Neville, Vice-President, in Charge of Manufacturing for the North American Manufacturing Co. of Cleveland, Ohio, received the Third Award of $2385. He described the redesign for welded construction of industrial type gas and oil burners. According to Neville, welded construction reduced weight 66%, unit cost approximately 45% and improved installation methods and increased burning efficiency.

Awards were for designs covering a wide variety of machinery, including metal cutting, electrical, conveying and pumping, compressing, tooling, processing equipment, construction, mining, petroleum, farming, woodworking and others.

Independent Oxygen Manufacturers' Assn.

At the Annual Fall Meeting of the Independent Oxygen Manufacturers' Assn., held at the Shamrock Hotel in Houston, Tex., on November 2nd to 4th, new officers and directors were elected for the 1954 term as follows:

President—Harold Macauley, Wolverine Gas Products, Inc., Saginaw, Mich.

Vice-President—Al Herzstein, Houston Oxygen Co., Houston, Tex.

Secretary—J. F. Wagner, The Burdett Oxygen Co., Cleveland, Ohio.

Treasurer—R. L. Swope, Southern Oxygen Co., Washington, D. C.

Executive Council—Marvin White, Welding Gas Products Co., Chattanooga, Tenn.; Tom Kean, Sierra Oxygen Co., Reno, Nev.; G. Morgan McBride, Western Oxygen, Inc., Seattle, Wash.; Fred Tillman, Campania Mexicana AGA, S.A., Mexico, D. F.; and R. G. Harrison, Welders Supply Co., Little Rock, Ark.

Alcoa Offers Color Welding Movie

A demonstration of the latest techniques in the welding of aluminum pressure vessels is a feature of the new color welding film available from Aluminum Company of America.

The 28-min 16-mm film, "Welding Advances with Aluminum," offers a comprehensive description of welding aluminum using both the tungsten arc and consumable electrode methods. Outstanding illustrations of the use of these inert gas methods are presented to demonstrate some of the many jobs they have simplified in manual, automatic and semiautomatic welding of aluminum. These include the pressure vessel welds, weld repair of castings and production of weldments among others.

The basic concepts of both tungsten arc and consumable electrode welding are explained in an animated sequence.

Described in the film are the services of Alcoa's research and process development facilities which are offered to customers for the solution of their welding problems. The viewer is taken on a brief tour of these facilities which include the famous Aluminum Research Laboratories and Alcoa's Joining Process Development Laboratory.

The film should be of equal interest to engineers, executives or welders.

"Welding Advances with Aluminum" can be borrowed for group showings. Requests for prints should be made on business letterhead to Motion Picture Section, 818 Alcoa Bldg., Pittsburgh 19, Pa.

View of one wing of the Welding Clinic area

Baltimore Welding Clinic

A very live and successful welding clinic was held in the warehouses of Earlbeck & Landrum, Inc., of 1023 Cathedral St., Baltimore 1, Md., on Thursday and Friday, November 19th and 20th, 2 to 9 P.M. each day.

As a result of direct invitation 685 interested guests attended the clinic during the two days of activity to view the 23 exhibits set up and manned by factory and distributors personnel.

The following welding equipment and supply manufacturers participated: Adjustable Clamp Co., All State Welding Alloys Co., American Pullmax Co., Arcair Co., Armor-Tuf Sales Corp., Atlantic Gas Flux Co., Bay State Abrasive Products Co., E. V. Bahrman, Inc., Black and Decker Mfg. Co., Contour Sales Corp., Dyer Weld Corp., Franklin Balmar Corp., Glendale Optical Co., Heath Engineering Co., Jewel Manufacturing Co., Lincoln Electric Co., Liquid Carbonic Corp., Mid-States Welder Manufacturing Co., K. Wm. Ostrom and Co., Rex Welder and Engr. Co., Unique Turntable Co., Welder Rental Div. of Earlbeck and Landrum, Inc., and Whitehead Metal Products Co.

Working demonstrations were provided by almost every one of the exhibitors who, through the educational facility provided by the welding clinic type of activity, brought firsthand knowledge to the representatives of the welding industry in regard to the availability of new welding equipment as well as more economic utilization of that equipment now being used in their plants. Each of the various welding, brazing and cutting processes were exhibited and a broad range of the various weldable methods were displayed and utilized in demonstration.

G. M. Visits Federal Machine and Welder Co.

Representatives of three General Motors Technical Subcommittees from General Motors Plants throughout the U.S. and Canada held their regular September meeting in Warren, Ohio, on Thursday and Friday, September 24th and 25th.

This meeting was held in conjunction with an inspection of the facilities and operations of the Federal Machine and Welder Co., Warren, Ohio, manufacturers of electric spot, projection, flash, seam, and portable gun type resistance welders and mechanical presses, etc.

Both sessions began in Federal's Main Office Building, Overland Ave, Warren, Ohio. Welcoming remarks by A. S. Blagden, President, and J. R. Barefoot, Vice-President, of Federal Machine and Welder Co., included points of interest regarding the organization, facilities and products of Federal.

Thursday the sessions were at the Trumbull Country Club and were for the benefit of the GM committee members.

The group made an inspection trip through Federal on Friday. At that time there was a presentation of papers by J. F. Deffenbaugh, Chief Electrical Engineer of Federal; F. A. Bodenheim, Jr., Sales Manager of Welders of Federal; and W. F. Longfield, Director of Warco Press Sales and Engineering of Federal.

In attendance were members of the G. M. Master Mechanics Welding Equipment Subcommittee, the G. M. Metallurgical Joining Processes Sub-Committee and the G. M. Plant Engineers Electrical Standards for Industrial Equipment Subcommittee.

French Institute of Welding

At the Annual Meeting of the French Institute of Welding in October 1953, its President, Prof. A. Portevin summarized the Institute's activities during 1952.

Instruction: The Welding College awarded diplomas to 14 welding engineers and certificates to three welding technicians. Besides the regular courses, there were two-week practical courses attended by 159 students, a teaching course for 35 professors, courses for personnel from the Navy, and the National Electrical Supply, and for 17 armament inspectors. There were also Sunday morning courses on welding processes attended by 190 students. The Professional Welding School had 59 pupils for the year 1952–53, each taking a three-year course. In June 1952, 22 students were awarded the professional welding certificate. A total of 788 students attended beginners and advanced courses. During the year 496 certificates of specialized welders were issued and 281 were renewed. Decentralization of instruction is being pushed, many courses being offered in the provinces.

Research: Increased research activity has been initiated as a result of an exchange of news with the Society of Welding Engineers. The Research Coordinating Committee consists of delegates from the laboratories as well as the French delegates to the International Institute of Welding. The armament fabricators continued their support of research on non-austenitic electrodes for air-hardening steels. The study of deep penetration electrodes has been completed for the Fabrication of Metallic Structures. The first phase of a study of the weldability of basic Bessemer steel has been completed. A start has been made on the second phase involving 30 heats. Several high-tensile steels have been studied for the Research Institute for Naval Construction. A study for the Bureau of Roads and Bridges was made determine whether it was possible to use rimmed instead of killed open-hearth steel for certain Code purposes. Other work has been done on butane tanks, sigma phase and the hardenability of steels.

The Laboratory's testing section issued 742 test reports on welding equipment, nondestructive testing, etc. Numerous pipe lines, penstocks and refinery installations were inspected, and many plans for welded construction were checked for

buildings, piping and aircraft. UNESCO has renewed its support through the Union of International Technical Associations of the abstracting service which resulted in 2331 abstracts being published in 1952.

Standardization: A standard for valves for acetylene generating equipment has been printed as well as two standards on terminology and classification of equipment for atomic hydrogen welding. Tentative standards have been issued on: Tensile, Ductility and Hardness Tests for Filler Metal for Gas Welding Steel; Filler Metal for Welding Steel, Cast Iron, Copper, and Brass, and for Braze Welding; Extra Pliable Cables for Arc Welding, and Cracking Tests for Covered Electrodes for Steel.

Nelson Stud Story

The phenomenal rise of the Nelson Stud Welding Co. of Lorain, Ohio, was described by representatives of that firm and the Reilly-Benton Co., representatives in New Orleans for Nelson, at the November meeting of the New Orleans chapter of the Producers Council.

A record attendance of over 200 prominent New Orleans architects, engineers and construction men turned out on the evening of November 11th at a famous New Orleans supper club to hear the story of the Nelson Stud Welding Co., as told by Al Lusch, general manager of Reilly-Benton in New Orleans, Jack S. Godley, vice-president of Nelson Stud Welding Co. and George Medsker, architectural consultant for the Nelson company.

A. A. "Bud" Boudousque, Field Representative for Reilly-Benton, right, instructs a guest in the fine art of shooting a stud with a Nelson Stud Welding gun

A cocktail party got the gathering underway, a feature of which was a group of displays set up by Reilly-Benton illustrating the wide scope of uses and applications of Nelson Stud Welding in the construction field. High spot of the exhibits was the actual "shooting" of studs by those present. A. A. "Bud" Boudosquie, Jr., and Jack Shepperd, field representatives of Reilly-Benton, instructed guests and members in the use of the extremely light and portable Nelson Stud Gun.

Following cocktails the business session of the New Orleans chapter of the Producers Council went into its program. Al Lusch delivered a short talk in which he described his company's role in the growth and distribution of Nelson equipment. The speaker referred to the large volume of Nelson stud welders and studs used in ship construction in New Orleans and Pascagoula, Miss., shipyards.

Next speaker of the evening was Jack S. Godley, vice-president of the Nelson Stud Welding Co. of Lorain, Ohio. He opened his remarks by terming the birth and subsequent phenomenal growth of his company "a tribute to the American free enterprise system." He traced the growth of the Nelson company from its birth in a two-car garage in 1939 in California by a Mare Island Naval Shipyard worker who hit upon the revolutionary stud shooting idea after laboriously hand-welding studs to the steel decks of aircraft carriers so that wooden flight decks could be secured.

By the end of World War II, according to the speaker, Nelson Studs were in extremely wide use in Navy and Maritime shipbuilding.

Godley went on to say that although Nelson was originally confined to only the marine field, the construction field now is an increasingly heavy user of Nelson Studs.

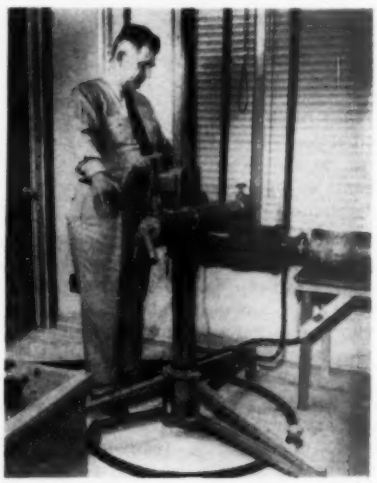
Final speaker of the evening was George Medsker, architectural consultant for Nelson. His remarks included a discussion of applications of Nelson Studs in the construction industry and the wide diversity in types designed for many jobs.

"Split Second Fastening," a sound and color motion picture telling the story of Nelson, followed the featured speakers of the evening.

In addition to the large number of prominent architects, engineers and construction men in the New Orleans area present at the meeting, a group of Nelson representatives from Lorain, Ohio, Houston, Tex., and other points were in attendance.

Tulsa Laboratory Installs Latest X-ray Unit

J. W. Phillips, Applied Testing Laboratory, Inc., 7822 E. Apache St., Tulsa, gets set to radiograph an oil drilling bit with a new Norelco X-ray unit which was recently installed.



The firm has doubled its staff and quarters in the past year because of increased demand in the southwest for industrial research and for services involving testing and X-ray inspection of pipes, welds and pressure vessels.

Central X-ray & Supply Co., Tulsa, local representative of North American Philips Co., Inc., installed the new MG 150 X-ray unit, latest equipment of its kind on the market. It is lightweight, compact and transportable.

Exceptional flexibility of this apparatus permits four types of X-ray tubes to be used.

REDUCE SPOT-WELDING REJECTS WITH DICE MICROHM METER
(Model 151-S)

MIL-W-6858 AND MIL-W-6860

This instrument, first developed by Dice, is now widely used in industry to maintain quality control and reduce rejects in the spot-welding of aluminum ... by checking the surfaces of sheets to see that they have been properly cleaned. The Dice Model 151-S Microhm Meter measures a resistance as low as 1/2 microhm in the low range to 750,000 microhms (in the highest range). A low resistance reading indicates that the metal to be welded is properly cleaned. The first Model 151 made by Dice is still in perfect working condition after almost five years of constant use. For free bulletin giving detailed information on how the Dice Microhm Meter can help you, write today.

J. W. Dice Co., Englewood 2, New Jersey
"Non-destructive Testing and Measuring Instruments"

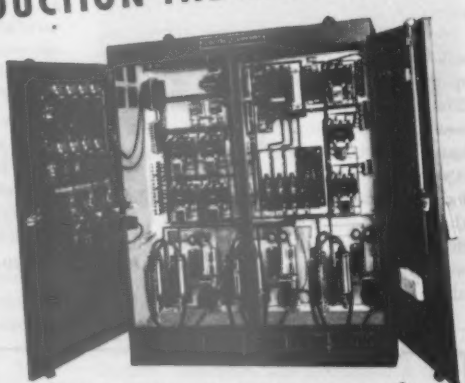
DESIGN LEADERSHIP

IN WELDER CONTROL FOR MASS PRODUCTION INDUSTRIES

A leading automobile manufacturer asked Square D to design magnetic and electronic control for a battery of 10 new multi-transformer welding presses. As many as 168 spot welds are made by one machine with 14 individually controlled timing periods in sequence.

Among the "must" requirements were:—welding current flow synchronized to prevent high starting transients and minimize stress on transformer windings; and a limitation of 1000 ampere current in each 3 phase line. *These 10 controllers are still providing trouble-free service after two years on the production line.*

Engineering counsel on any electrical control problem is available through Square D field offices in all principal cities.



One of the completed control panels *Because Square D's line of control is so complete, this entire unit was designed using only standard devices, accessories and electronic sub-assemblies.*

SQUARE D COMPANY

The photo (page 76) shows a typical application for the Rod-Anode tube. Due to its unusual design, it can be inserted in a pipe or vessel and a 360-deg weld may be x-rayed with one shot. Normally a 360-deg weld would require several exposures. The apparatus shown is capable of penetrating up to 2 in. of steel.

Lincoln Arms for Cost Crusade

To arm its field men for what it calls its 1954 Cost Crusade, the Lincoln Electric Co. of Cleveland recently called into its factory all of its District Managers from all sections of the country. Meeting with members of Lincoln's development and application engineering staff, these 41 managers studied for three days how new developments in welding equipment could be successfully applied to reduce the cost of manufacturing and maintenance in metal working industry. Lincoln's approach during 1954 to the problems of industry will be to offer the service of its field engineers in analyzing how welding methods can be introduced or improved to help reduce costs.

Several new developments in both machines and electrodes were studied by the district men with an eye to their cost reducing possibilities. Lincoln's new powdered metal electrode, Jetweld, was demonstrated, and the managers welded with it themselves to prove its cost reduction possibilities. With Jetweld, welding speeds are claimed to be twice as fast as with other types of manual electrodes. Weld quality is comparable to automatic welds.

A new 6012 electrode designed for higher welding currents, and consequently higher speeds, was also studied along with new fluxes for automatic hard surfacing. The new fluxes represent a new approach to hard surfacing in that hard surfacing is done with mild steel electrodes. The hard-surfacing alloy materials are added to the weld metal through the flux. The fluxes provide more precise control of weld deposit and are lower in costs than alloy wire.

Cost Crusaders: Lincoln Electric District Managers, from all sections of the country

New techniques for the application of Twinarc welding were reported from the field. Reductions in welding time up to 50% have been made possible by adapting standard welding heads to use two small wires rather than a single larger wire and, hence, welding with two arcs.

Field experiences in presenting new developments in welding clinics were also discussed and practiced.

Note on the Bibliographical Bulletin for Welding

The publication of the *Bibliographical Bulletin for Welding* was the first important achievement of the International Institute of Welding and it meets a general need for information and documentation on the part of all those who are concerned with the welding techniques and allied processes.

The Bulletin contains systematic, clear, precise and methodical abstracts of books, news and articles appearing in the technical publications of the whole world on the various welding processes (electric arc, resistance, oxyacetylene etc.), oxycutting, surface hardening, metal spraying, building up, etc. in all their applications. The

(*Continued on page 95*)

Plan To Attend The AWS Welding Exposition

Buffalo, N. Y. May 5–7, 1954

WELDING ENGINEERS AND METALLURGISTS

Leading organization in welding technology needs several capable graduate engineers for applied research and development activities in resistance welding, all fields of arc welding, and in brazing and soldering. Excellent promotional opportunities in a stable, progressive concern employing about 2200. Apply now for prompt, confidential consideration to

BATTELLE MEMORIAL INSTITUTE
505 King Avenue
Columbus 1, Ohio

Metallurgy Executive

Excellent opportunity for experienced physical metallurgist to direct welding research section. Graduate study in metallurgy and practical experience essential. Permanent position with internationally known research organization offers unusual opportunity for personal and professional advancement. Send résumé to:

Mr. J. A. Metzger
Armour Research Foundation
of Illinois Institute of Technology
Chicago 16, Illinois

NEW PRODUCTS

Ampco-Weld Flux

A new powdered flux for use, primarily, in the welding of Ampco 8 and other aluminum bronze sheet and plate has been developed by the Research laboratories of Ampco Metal, Inc., Milwaukee, Wis. It may be used with the inert-gas processes and bare Ampco-Trode filler rods in all grades.

Ampco-Weld Flux will insure the removal of oxides from the weld metal and reduce the surface tension allowing the deposit to flow into the side walls more uniformly thereby producing a sounder deposit of improved appearance. Full penetration can be secured in straight butt joints at lower welding currents and preheats. The use of Ampco-Weld Flux is essential to the successful welding of light gage aluminum bronze sheet.

Ampco-Weld Flux is available in 1-lb jars to all Ampco distributors.

Gamma-Ray Fluoroscopy

The idea of instantaneous visual X-ray examination without the use of photographic plates was conceived by Thomas A. Edison late in the 19th Century. His invention of the fluoroscopic screen created this science which is now widely used in medical diagnosis.

With the advent of atomic energy, very intense sources of radioactive materials have become available at reasonable prices. These materials radiate gamma rays which are identical to very penetrating X-rays. In theory, therefore, a very intense source of radioactive materials should be equivalent to a "hard" or penetrating X-ray tube.

This idea was the basis of the invention by Radioactive Products, Inc., of a gamma-ray fluoroscope and is believed to constitute one of the more important developments in this field since its origin. Of particular significance is the fact that gamma rays from materials such as radioactive cobalt are more penetrating than X-rays from all but the fabulously expensive multimillion volt machines. So penetrating are these radiations that only half of them will be absorbed in passing through $^3/_4$ in. of steel.

This new instrument, which stands 7 ft high and contains its radioactive source in a steel-cased cylindrical lead shield 18 in. in diameter, has aroused considerable interest among automobile manufacturers and foundry men. It may prove especially valuable to the aircraft industry where inspection of parts is a necessarily thorough and painstaking task.

For further information write to Radioactive Products, Inc., 443 W. Congress St., Detroit 26, Mich.

Soldering Paste

A new step-saving soldering paste compounded of flux and solder is applied cold, then heated, any way, to 375° F to seal, join or tin most common metals except aluminum.

It has just been announced as All-State Soldering Paste by All-State Welding Alloys Co., Inc., 249–55 Ferris Ave., White Plains, N. Y.

The company, characterizing this product as a good one especially in terms of quality, expects it to have varied application in manufacture, construction and maintenance—and, due to its ease of application without even a soldering iron, in the home as well. Applications already observed include soldering of multiple wire assemblies, radiator work, tinning of utensils, internal tinning, sheet metal work, tubing work, auto body repairs and, when formulated with a special alcohol-resin flux, a wide range of electrical work. In tubing work, pressure tests to destruction (up to 6500 psi) failed to break soldered joints.

Electrode Welds Cast Iron "Cold"

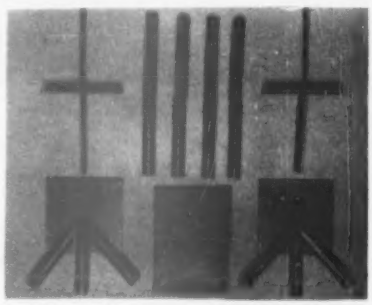
A new electrode, trade-named XYRON, with a specially designed coating, has been developed for welding cast iron by the Eutectic Welding Alloys Corp., Flushing, N. Y.

The operator will find this electrode is the answer to his many cast-iron welding problems. There is an unusual density of deposits, and cracking, cross checks, etc., have been practically eliminated. The amperage requirements are extremely low; the $^3/_{32}$-in. electrode operating on 35 to 75 amp. This all-purpose electrode for cast iron can be used for building up, repairing breaks or cracks, fabricating, etc., and deposits have maximum machinability. All position welding is possible and repairs may be made in position without dismantling or special preparation. Welders with little experience on cast iron can handle this electrode because the arc length is not as critical as with conventional electrodes and high-tensile, color-matching, machinable deposits will result when recommended procedures are followed.

An illustrated booklet will be sent free of charge. Write for your copy to Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y.

Test Kit

CBC Welding Corp., 422 E. 102nd St., New York 29, N. Y., announces the introduction of the new Welders' Test Kit conforming to Air, Navy, Ordnance Specification MIL-T-5021. The use of this kit saves time and money since everything necessary for Government certification of welders is included. The kit consists of 2 clusters, 1 plate, 2 crosses, 2 sets of tubes; all are made of chrome molybdenum. Also included are all of the necessary application forms. The CBC Welder's Test Kit can be used to practice as well as to take the test by Government Inspectors. This kit is shipped from stock.



Complete literature, information and prices are available by writing to CBC Welding Corp., 422 E. 102nd St., New York 29, N. Y.

Cast-Iron Electrode

The Tennessee Fabricating Co., 1490 Grimes, Memphis, has developed a new welding electrode especially for welding cast iron to steel and is making it available to the trade, Abe Sauer, president, has announced.

"We have always used expensive nickel rod to weld steel to cast iron," Mr. Sauer said. "In our production the large quantity of rod used represented an appreciable item of cost. So we developed our own welding rod specifically for welding cast iron to steel and have cut our cost over a third."

Mr. Sauer said that the T.F.C. electrode will not do all a nickel rod will do, but it will give a good weld between steel and cast iron with good penetration and

WELDING ARCS NEWS

New G-E Fillerarc Equipment Widely Acclaimed by Industry

Dependable, low-cost operation and wider application praised in new consumable electrode gas-shielded welding equipment

Demand for new G-E Fillerarc equipment for consumable electrode gas-shielded welding is the greatest in G-E Welding history. At the Metals Show, at G-E Distributor demonstrations, and in customer plants, Fillerarc equipment has proved its merit as the leading equipment for this high-speed process.

BURN-BACK AND STUBBING MINIMIZED

Of course customers are amazed by the high speeds of Fillerarc equipment and by how fast operators pick up Fillerarc technique. But their greatest praise is for reduction of burn-back and stubbing problems which plagued operators of other equipment.

WELDER, GUN, WIRE-DRIVE FORM PACKAGE

Ease of operation and minimum trouble are built-in features of new Fillerarc equipment. Here's why:

Fillerarc Welder has a self-regulating generator with a rising volt-ampere characteristic which maintains desired arc length automatically. What's more, you can change wire speed even while you are welding and the current is always right.

Fillerarc Gun pulls wire into gun, permitting the use of smaller wire. Result: you can weld thinner sections than ever before possible.

Fillerarc Wire-drive is powered by a Thy-mo-trol* drive and dynamically braked to give you precise wire-feed control. Dial gives continuous wire-speed indication—no need to time and measure.

If you haven't yet seen Fillerarc equipment in action, contact your G-E Welding Distributor today. He can give you full data and arrange a demonstration. He's listed here and in the yellow pages of your phone book under "Welding Equipment—General Electric." General Electric Co., Schenectady 5, N.Y.

*Reg. Trade-mark of General Electric Company 710-15

***P. S.:** Your G-E Welding Distributor can furnish filler wire for this process. Ask him for a quotation to your specifications.*

Now—a Plastic Ventilated Helmet

The famous G-E ventilated helmet is now available in plastic to give you the last word in comfort, convenience, and long life.

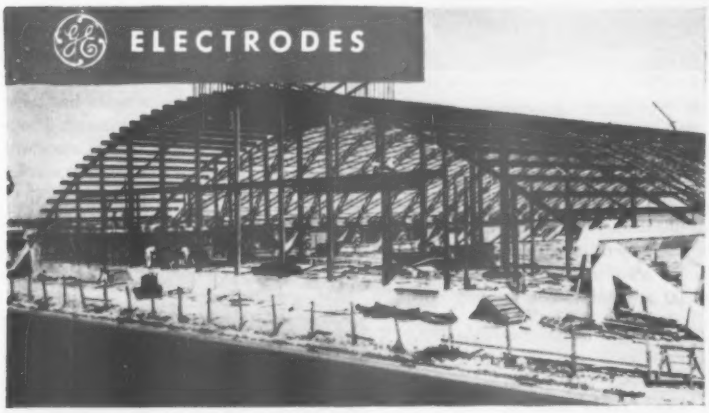
FOR YOUR COMFORT

- G.E.'s famous ventilated design provides a cool head on the job.
- Moisture-proof headgear assumes head shape exactly—but won't warp.
- Ratchet-type device makes exact head-size adjustment simple.
- New four-position stop meets vertical and overhead needs, too.

FOR LONG LIFE

- Seamless plastic construction has excellent strength.
- Plastic shell is moisture-proof and heat-resistant.

Avoid fatigue, get real comfort and convenience on the job with the new G-E plastic ventilated helmet—lift-front or stationary type.



Columbia Iron Works Selects W-612A

In choosing an electrode for shop-welding structural roof joists, Columbia Iron Works of St. Louis was looking for the best available combination of weld quality, speed, and usability.

After tests, they selected G-E Type W-612A electrodes as tops for this job. Columbia is mighty pleased with the results, too, because W-612A helped them complete delivery in 20% less time than originally estimated.

This successful application of W-612A—one of more than 70 arc-welding electrodes supplied by G.E.—is another example of "balanced electrode design for best over-all results."

You'll Find the Best Electrode for Your Job in the G-E Line—Most Complete in the Industry

G-E WELDING DISTRIBUTORS

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo, Sterling—Hendrie & Bolthoff

Connecticut: Hartford, New Haven—Harris Sales & Service

Florida: Hollywood—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Hutchinson—Kopper Supply

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City, Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales Corp.

New Mexico: Albuquerque—Industrial Supply Co., Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; New York—Welding Sales Corp.; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Hereford—Tex-Air Gas; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—Nortex Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

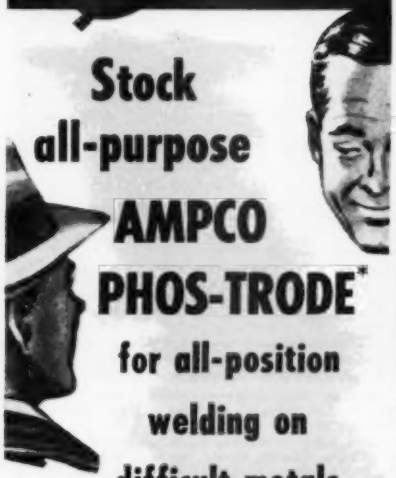
Alaska: Anchorage—Northern Supply

Canada: Tornoto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

GENERAL ELECTRIC

Silicon-bronze water heater tanks fabricated with corrosion-resistant Phos-Trode.



Stock all-purpose AMPCO PHOS-TRODE* for all-position welding on difficult metals

MOST any welding job in your plant is quick and easy with Phos-Trode. You get sound welds joining tin bronzes, cast iron, cast iron to steel, bronze to steel, copper, malleable iron, brass, and many others. You get good deposits in any position—flat, vertical, or overhead. Low spatter-loss and high deposition rate give you faster, better-looking welds at lower cost.

Tough jobs—like the welding of the silicon-bronze home water-heater tanks shown — are a cinch with Phos-Trode. No edge preparation is necessary. Welds are clean — free from pitting and porosity. Deposit and fusion zone cracking is ended—repairs and rewelds are at a minimun.

Stock Phos-Trode and lower your costs — with faster, better welding on difficult metals. Available in 6 sizes 3/32" to1/4". Order your supply of Phos-Trode now.

*Reg. U. S. Pat. Off. W-126

AMPCO METAL, INC.

AMPCO

Dept. WJ-1

Milwaukee 46, Wis

West Coast Plant, Burbank, California

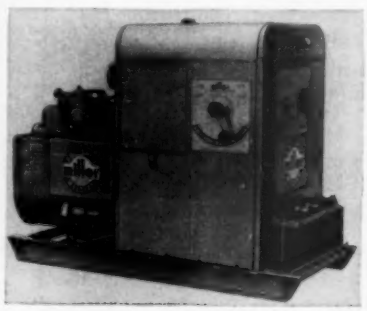
excellent fusion. There is almost a total absence of spatter, he said.

T.F.C. electrodes are available at a saving up to 35% of the cost of the expensive rods commonly used for welding cast iron to steel.

T.F.C. rod has a nickel and copper content and produces a tensile strength weld up to 65,000 psi. It is available in $^1/_8$ and $^5/_{32}$-in. sizes, according to the company.

Power Supply

A 300-amp d-c field welding and a-c power-supply unit that sets new standards for compactness of construction and convenience and flexibility of operation is announced by Miller Electric Manufacturing Co., Appleton, Wis. This self-contained power package consists of a high-efficiency three-phase rotating field alternator driven by the new 20-hp Onan



Model CW 2 cylinder, air-cooled gasoline engine. The output of the alternating-current generator is available to easily supply 10 kw of standard, 60-cycle a-c power for three-phase and single-phase power applications. For welding, the output of the generator is passed through high-capacity selenium rectifier giving the operator 300 amp of direct welding current.

Electrode Holder

Two new "coolie" welding electrode holders, announced by Cam-Lok, Division of Empire Products, Inc., feature special construction, with inside mechanism *suspended* in the handle for better ventilation. This insures cool operation.

Lightweight, yet ruggedly constructed, the "coolie" electrode holders are offered in either the straight-nose or the offset pug-nose holder types. Both take up to $^1/_4$-in. rod. For toughness and high conductivity, the metal parts of the holders are made from high copper content aluminum bronze. Cable is firmly secured with large $^1/_2$-in. setscrew or can be solder attached.

The unbreakable Cam-Lok holders are fully insulated with the latest in tough, lasting materials, heatproof and breakproof. The handle insulation completely

covers and protects the operating mechanism. Tough, heat-resistant pads for both jaws and both holders are completely interchangeable and easily replaced.

The Cam-Lok holders have been specifically designed with the convenience of the welding operator in mind. The handle is the right size for fatigue-free grip. The holders can be operated with one hand, without releasing grip on the handle. Rod is loaded easily, so that the operator is ready to resume welding without lost time or motion.

For complete information, write for Cam-Lok Bulletin No. 111, Cam-Lok, Division of Empire Products, Inc., P. O. Box 98, W-59, Cincinnati 36, Ohio.

Electrode Oven

A new, completely portable electrode oven, capable of holding a full 10-lb package of 14-in. low-hydrogen, stainless steel or other special alloy electrodes has been designed and produced by Phoenix Products Co., manufacturers of the standard DryRod Electrode Ovens long used by welding shops and departments.

The new model is less than $20^1/_2$ in. high, and $8^1/_4$ in. in diameter, and like

the 300- and 900-lb models in the DryRod line, the midget size unit employs the cylindrical shape feature for maximum even heat distribution by convection. Called the Model 10 DryRod, it stands either upright or on its side, without danger of tipping or rolling. Operating on 110-v a-c, the oven comes fully wired and is said to maintain a continuous, even flow heat which affords complete protection for all standard high-strength electrodes.

DryRod's manufacturer foresees wide application for the new, low-priced model on diversified operations in large plants and shipyards, on mobile welding service units, and as regular equipment for welding departments and smaller ships where low-hydrogen production is not a primary operation and it is felt that standard models are too bulky.

Cam Clamp

"SESCO" Cam Clamps offer the unique advantage of maintaining positive holding pressure and secure clamping action, even on such varying stock thicknesses as are found in castings and forgings, according to the manufacturer.

SESCO Cam Clamps eliminate the need for adjusting hold-down bolts or other special accessories, because the cam surface makes allowance automatically for stock thicknesses varying as much as $^1/_8$ in.

The clamps are of rugged all-steel construction with all working surfaces machined to close tolerances and hardened. Their heavy construction and precision assembly, along the cam feature, allow the clamps to withstand severe vibration, making them ideal for many milling operations as well as for the usual clamping applications.

SESCO Cam Clamps are available in four standard sizes. Literature and tracing templates are offered without obligation by the manufacturer: Special Engineering Service, Inc., 8161 Livernois Ave., Detroit 4, Mich.

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Diesel-Engine-Driven Welder

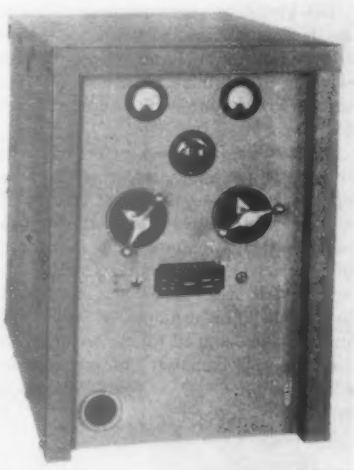
Newest addition to the Hobart "Multi-Range" welder line is a Diesel-engine-driven arc welder of 300-amp capacity, especially designed for locations where electric power is not available and a minimum operating cost is desired.

Powered by a General Motors Model GM-2055, 2-cycle unit injection Diesel engine, that features oil cooling, displacement blower, fuel filteration and easy starting, this welder will cut fuel costs considerably. The engine has a piston displacement of 141.8 cu in. and is rated at 67-hp at 1500 rpm.

Equipped with patented "Multi-Range Dual Control" and exclusive remote control, this new welder permits the operator to make fine voltage-ampere adjustments right at the work, eliminating unnecessary steps from the work to the machine and back again. Its 1000 combinations of voltage and ampere permit the operator to select the right arc intensity to suit any job. Other features include separate excitation and two-way ventilation for a smoother, more productive arc at all current values. For complete details write the Hobart Brothers Co., Dept. DW, Hobart Square, Troy, Ohio.

Constant Voltage Welder Announced

Designed specifically for powering submerged-arc, inert-gas (sigma) and other types of automatic welding processes, a new 1000-amp rectifier-type d-c welder is now in production by the Glenn Co., Oakland, Calif.



Designated as the Model 1000UV-40, the new unit is rated at 1000-amp continuous duty, an infinitely variable preset arc voltage range of 18 to 42 v. It operates on 3-phase, 60-cycle, a-c power, 240 or 480 v. Efficiency is 85% or better and power factor 90%.

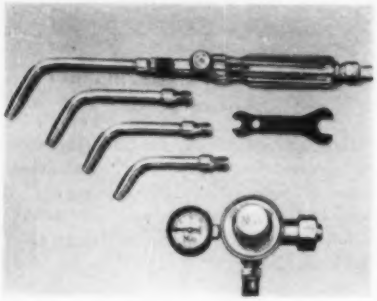
Because arc voltage can be preset at the machine and remains constant during welding, no external voltage controls are required. Rate of deposit is regulated by rate of rod feed. Speed regulation of the rod feed roll motor is the only external control used. Uniformity of arc voltage is said to eliminate bad welds due to poor fit-up, reduce faulty welds, and increase production through higher and more uniform deposit rate.

The "stepless" 18- to 42-v arc voltage range permits use of the new unit for submerged-arc, inert gas, and hand-operated automatic welding processes, as well as for automatic stud welding and compressed air-carbon arc cutting and gouging operations.

Complete information can be obtained from the Glenn Co., 3134 E. 10th St., Oakland 1, Calif.

Handy Maintenance Kit

The "Sod-R-Braze" air-acetylene apparatus, manufactured by National Cylinder Gas Co., 840 N. Michigan Ave., Chicago 11, Ill. permits quick maintenance and repair work on all types of jobs where fusion welding is not essential.



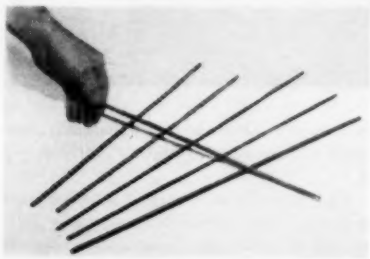
The complete outfit consists of torch, tips, hose and adjustable regulator. Used with NCG's 40 cu ft acetylene cylinder, weighing approximately 32 lb net, it is easily portable within the shop or to outside jobs.

The torch can be used for brazing with silver or copper alloys, soldering and heating. It is particularly suitable for work on sheet metal, steel piping, copper tubing, electrical apparatus and automotive and electrical equipment. Despite the fact that it uses no oxygen, it permits fast work. For example, it will silver braze $^3/_{16}$-in. copper tubing to brass fittings in approximately 38 sec and will solder the same type of joint in about 26 sec.

The torch has a grooved plastic handle, leakproof valve and is equipped with a pilot light. It can be turned off and on, adjusted to proper flame, or to pilot light, with the thumb of the hand holding the torch. An 8-page catalog describing Sod-R-Braze apparatus is available.

Repairing Manganese Steel Castings

A new manganese-nickel steel welding rod for repairing or building up worn or broken manganese steel castings is announced by Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich. It can also be used as a build-up material prior to applying Colmonoy hard-facing alloys to manganese steel parts.



Called Walmang, the new material has been developed to provide an austenitic manganese steel welding rod that produces weld metal having the same manganese content, work hardenability, and wear resistance as cast 12% manganese steel.

Walmang weld metal has excellent fusion, penetration and density characteristics, thus minimizing the effects of welding heat on the parent metal.

This new welding rod can be applied as a weld deposit for repairing of salvaging a wide range of manganese steel castings commonly specified by the railroad, mining, cement, construction equipment and steel industries. It can also be used as weld metal to attach cast replacement wear parts to manganese steel castings.

Transformer Parts

Though the General Electric Co.'s power transformer plant at Rome, Ga., is still incomplete, welders are already working on transformer parts. Shown are tube units being welded. The tube units

are placed on welding fixtures so that welders are required to do only down-hand welding. When an end being welded is finished, the fixture is rotated and the opposite end welded without the welder being required to move. A setup similar to this will be used when the plant is in full operation. The first transformer to be manufactured here is scheduled to come off the line in January 1954.

Automatic Welding Fixture

For cost-conscious metal fabricating companies that are doing or contemplating automatic welding, here is a completely flexible fixture. C. B. Herrick Mfg. Corp., 1935 Euclid Ave., Cleveland 15, Ohio, announces a ram-type machine featuring ruggedness, precision and versability, which will produce faster, better and lower cost automatic welding. This model is the CB 6X6.

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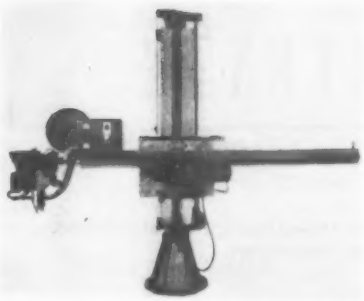


The tubular lateral ram, with automatic head attached, travels 6 ft 6 in. over the positioned or rotating work. Variable-speed drive provides welding speed range of 0 to 100 ipm. Motorized vertical adjustment ranges from 13 in. to 6 ft. The tubular column, containing counterweight, and the ram rotate 360 deg. The head mounts easily on the ram.

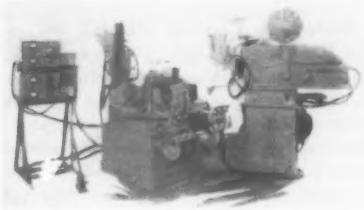
The CB 6X6 may be mounted on a carriage to travel longitudinally on special track. Any length track may be used, coming in 10-ft lengths. Track speed is also variable from 0 to 100 ipm.

Welding generators and flux recovery equipment may be mounted on the carriage. All fixture control is centralized in a small hand pendant.

Two larger models are available, one with 8-ft lift and 10-ft ram travel, the other with 10-ft lift and 12-ft ram travel.

Automatic Welding Machine

Morton Special Bearing Shell Welding Machine offers full automation with high production. The machine is designed to make both internal and external welds in heavy wall bearing shells. Manual air-operated flux backing is built into the clamping fixtures for internal welding.



The operating and indexing cycles are completely automatic under operator control. The operating cycle of either or both head slides, with rapid traverse, variable controlled speed during welding and rapid retraction, is automatic. Hydraulic power is used to index the table into the three positions against fixed adjustable stops. The index and welding motions are electrically interlocked to protect against improper sequencing.

Manual air-operated cast-bronze clamp shoes hold the work at each of the three stations. Other features include automatic light beam gaging of the shell seam and automatic ejection of the welded bearing shell. For further information write to Morton Manufacturing Co., Muskegon Heights, Mich.

Dalweld Welding Cable

In a new all-purpose arc-welding cable which has been announced by Dalweld Co. 1 Bertel Ave., Mount Vernon, N. Y., a tough Neoprene compound is used to give the cable greater durability under severe service conditions. Neoprene is used because of its high resistance to heat, hydrocarbons, oils and greases as well as to acid attack. The compound used for the jacket meets ASTM Specification D 752. The conductor in Dalweld welding cable is composed of fine pure copper wires, stranded so as to give extra flexibility, which is a distinct help to the operator whether he is working on light assemblies or heavy sections. The separator is a strong paper, thin enough so that it does not impair the flexibility. This construction results in a cable which will stand up under the most severe working conditions and still be easy to handle. Dalweld cable is packed in 250-ft coils or 1000-ft reels; furnished in sizes from No. 6 to No. 4/0.

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Field Erection of Pipe

Bethlehem, Pa.—The regular monthly dinner meeting of the *Lehigh Valley* Section was held on November 2nd at Walp's Banquet Hall, Allentown, with an attendance of 42 at dinner and 85 at the technical meeting. R. T. Pursell AWS of the Stone & Webster Engineering Corp., New York, presented a semitechnical paper on the subject "Intert-Arc-Gas-Shielded Arc Welding as Applied to the Field Erection of Pipe Welding."

Coffee speaker was E. L. Durkee, AWS, of the Bethlehem Steel Co., who told some "Tales from Texas."

Membership Drive

Boston, Mass.—The November dinner meeting of the *Boston* Section was held at the Westinghouse Auditorium on November 9th.

After a dinner catered by Dora A. Ferguson, William G. Read, Field Secretary of the Savings Bank Life Insurance Council, gave an interesting coffee talk of the various aspects of "Life Insurance in Estate Planning."

To launch the membership drive, a drawing was held to determine the recipient of a free Associate Membership in the AWS for one year. Since the winner is a member, John H. Williams, the Membership is to go to some eligible person of his choice. Membership blanks were then distributed to all present with the exhortation to go out and bring in at least one new member each.

Donald P. Faulk AWS, Manager of the Engineering Applications Section of the Raytheon Manufacturing Co., then presented an interesting paper on the subject of "Electrostatic Stored Energy Welding." Slides illustrated several unique applications of this method as developed by the Raytheon Co., including the welding of heat-treated steel parts without harming the treated surfaces.

Brazing Tool Steel

Bridgeport, Conn.—The November 19th dinner meeting of the *Bridgeport* Section was addressed by W. L. Kennicott, Chief Engineer, Kennametal, Inc., Latrobe, Pa., on the subject "Brazing of Hard Carbide Tool Tips and Parts." Mr. Kennicott used slides to illustrate his semitechnical talk.

Coffee speaker was Chris Wesche, Area Director of Civilian Defense.

Tooling for Welded Design

Buffalo, N. Y.—John Mikulak, AWS, of the Worthington Corp., Harrison, N. J., was the guest speaker at the October 29th dinner meeting of the *Niagara Frontier* Section, held at the Hotel Sheraton. One hundred and ten members and guests were present at dinner and 123 at the meeting. Mr. Mikulak's subject was the "Tooling and Fabrication for Welded Design."

Brazing

Chicago, Ill.—The *Chicago* Section, at its October meeting held on the 16th, was addressed by R. E. Ballentine, Manager of the Westinghouse Electrode Plant. Mr. Ballentine presented an excellent extemporaneous talk on the subject "Brazing." Forty members and guests were present at dinner and 68 at the meeting.

Aircraft Welding

Cincinnati, Ohio.—Gordon Parks AWS of the Solar Aircraft Co., Des Moines, Iowa, gave an illustrated nontechnical talk on "Aircraft Welding" at the October 27th meeting of the *Cincinnati* Section held in the Engineer and Scientist Bldg., with an attendance of 75.

Rigid Frame Design

Cleveland, Ohio.—One hundred and seventy-five members and guests of the *Cleveland* Section were present on November 11th at the Mather Room of the Allerton Hotel to hear a leading authority talk on the subject of "Rigid Frame Design." Martin P. Korn AWS, Consulting Engineer, Giffels & Vallet, Inc., Detroit, presented an unusual and stimulating illustrated lecture on "Adventures in Rigid Frame Design." This was a fast moving story of steel rigid frames for buildings varying from the largest to the smallest ever built. Several structural failures were reviewed as well as stress behavior in knees, column bases and foundations. Comparison was made between welded, riveted and concrete types.

Mr. Korn is at present directing design of the proposed Convention Hall & Exhibits Building for the Detroit Civic Center, a twenty-million dollar project, one of the largest of its kind in the world.

Coffee speaker was M. B. McCammon, Assistant Chief, Internal Revenue Department, U. S. Treasury, who gave some interesting highlights of the closed files of the Department.

Symposium

Cleveland, Ohio—The 14th Annual Symposium of the *Cleveland* Section was judged to be the most outstanding and constructive in its history. Over 600 members and guests heard nationally known technical speakers discuss important new developments in the welding industry.

Also judged outstanding were the Educational Exhibits, supervised by Herb Hinkel, G-E sales engineer. Here manufacturers, distributors and users of welding equipment and accessories presented and saw latest developments in techniques and equipment.

The Symposium was dedicated to William H. Loveman, president of Burdett Oxygen Co., for contributing to the success of the Cleveland Section. Mr. Loveman's company recently celebrated its 30th anniversary.

Choosing Welding Process

Dallas, Tex.—An excellent presentation on the subject "Economics and Technical Aspects of Choosing a Fusion-Welding Process for Production Welding" was given by A. W. (Andy) Anderson AWS of the Linde Air Products Co. at the October 23rd meeting of the *Dallas* Section held in the Auditorium of the Dallas Power & Light Company.

Resistance Welding

Dayton, Ohio.—Fifty members and guests of the *Dayton* Section were present on November 10th to hear J. Ray Wirt AWS of the Delco Remy Division, GMC, Anderson, Ind., give an extemporaneous, semitechnical talk on "Resistance Welding." Mr. Wirt's talk emphasized the increasing importance that manufacturers are placing on material handling and operator comfort in contrast to the former concern with the electrical components alone.

Through the courtesy of the General Electric Co., a sound color film, entitled "This Is Resistance Welding," was shown.

Electricity and Welding

Denver, Colo.—New methods, applications and processes were covered in a talk given at the November 10th dinner meeting of the *Colorado* Section by Jim Morroni

of the Electric Equipment and Engineering Co., Denver, on the subject "Electricity and Its Relation to Welding." The meeting was held in the Festival Room of the Oxford Hotel.

"The Story of Nickel" was the title of a 16-mm sound film shown before the meeting through the courtesy of the Ideal Pictures Co.

Filler Arc Process

Erie, Pa.—R. W. Tuthill AWS of the General Electric Co., Welding Div., Fitchburg, Mass., gave an extemporaneous talk to the *Northwestern Pennsylvania* Section at its dinner meeting held on November 18th at Howard Johnson's Restaurant. Mr. Tuthill spoke on the Filler Arc Process, a revolutionary development in the field of inert arc welding.

New opportunities for cost savings and quality improvement are being offered now in the field of inert-gas-shielded, consumable-metal-arc welding.

Recent developments in equipment for this type of welding feature new techniques for feeding and controlling wire speed and arc length.

These new developments considerably reduce the operator skill requirements for obtaining quality welding, and at the same time expand the field of application by making it feasible to weld with wire from 0.030 to 0.093 in. diam on aluminum and other metals.

Liquid Oxygen Demonstration

Grand Rapids, Mich.—The October meeting of the *Western Michigan* Section held on the 26th was attended by 45 members and guests. R. L. Thuerbauch of the National Cylinder Gas Co., Evansville, Ind., gave a liquid oxygen demonstration. Mr. Thuerbauch started his demonstration by saying that he did not intend to perform any magic, but with the fried eggs, frozen rubber balls, frozen gold fish and the like it was a bit mystifying. The speaker brought out many points about the manufacture of oxygen and the safety measures necessary and also touched upon the subject of Hydrogen and Hydrogen and Oxygen mixed. His subject was very well received and enjoyed by all.

The coffee talk was presented by three members of the Section who each related facts about the company they worked for and products manufactured. They were Walker Smith of the American Seating Co., Frank Slack of the Metal Office Furniture Co. and Lem Harris of the Holland Furnace. The purpose of the coffee talk is to acquaint all the members with the various manufacturing concerns and products manufactured in the Section.

Welded Highway Bridges

Houston, Tex.—Percy V. Pennybacker, new elected Chairman of the Austin Division, connected with the Texas Highway Department, Bridge Division, Austin, addressed the November 24th dinner meeting of the *Houston* Section, on Welded Highway Bridges—Design and Construction in Texas. This was an excellent, semi-technical talk illustrated with slides.

A sound, color film, entitled "Wings for the Hunter" was shown before the meeting through the courtesy of the Humble Oil & Refining Co.

One hundred and nine members and guests were present at this meeting held at the Ben Milam Hotel.

Electrodes

Houston and Austin, Tex.—H. F. Reid AWS of the McKay Co., York, Pa., gave a very interesting and enlightening talk entitled "It Isn't Mud" covering the chemical formulas used in coating both carbon and stainless steel electrodes and some of the functions these chemicals perform.

This was the regular dinner meeting held at the Ben Milam Hotel in Houston on October 28th and at Randy's Circle R Barbecue, Austin on October 29th. Approximately 110 members attended the Houston meeting and 45 attended the Austin meeting.

Resistance Welding

Indianapolis, Ind.—Resistance Welding was the subject of an excellent presentation given by Jack Ogden AWS of the Fisher Body Division, GMC, at the October dinner meeting of the *Indiana* Section held at Buckley's, Cumberland, Ind., on October 6th. Mr. Ogden's talk was supplemented with high-speed movies and slides.

Fifty-seven members and guests were present.

Plant Tour

Kansas City, Mo.—The *Kansas City* Section held its monthly dinner in Fred Harvey's Pine Room with 43 members and guests present. Following the dinner, a short business meeting was held.

The meeting was then adjourned to the General Motors Buick-Oldsmobile-Pontiac assembly plant in Kansas City, Kan. Fifty-five persons participated in a very interesting plant tour which covered the assembly of these automobiles from the body subassemblies to the final inspection. Many interesting welding procedures and practices were observed. The tour which lasted approximately 90 minutes was completed by 10 o'clock.

First Annual Ladies Night

Long Beach, Calif.—For the first time, the *Long Beach* Section held a meeting devoted to the wives of the members. This special meeting was held on Friday evening, October 30th, in the Marine Room of the Wilton Hotel overlooking the Pacific Ocean in Long Beach.

The members went all out to entertain the ladies with special entertainment, orchestra dinner music, the best steak and lobster dinner available, cabaret style with dancing throughout the evening. The ladies were furnished with corsages and many door prizes.

One hundred and forty-two members and wives were present. This first Annual Ladies Night was a big success, and it looks as though another Ladies Night will be held in June for the last meeting of the season. It is planned to establish at least one meeting a year as Ladies Night. This is to be an annual Long Beach Section event.

Low-Hydrogen Electrodes

Los Angeles, Calif.—At a meeting of the Aircraft and Rocketry Welding Panel of the *Los Angeles* Section, held on Oct. 1, 1953, Arthur L. Wynn, Welding Engineer, Harnischfeger Corp., Los Angeles, reported on the use of low-hydrogen electrodes with respect to underbead cracking. To illustrate the effectiveness of low-hydrogen type electrodes, he showed a slide which compared the weld cross sections of several different electrode stringer beads on one SAE 4130 steel bar. The comparison showed that electrodes coated with organics, titanates and iron oxide produce underbead cracking more easily than electrodes coated with calcium carbonate, calcium fluoride and titanate mixtures. The essence of this example coupled with a briefing on types of coatings revealed that electrode coatings having any organic compounds are more prone to underbead cracking than electrodes coated with inorganic compounds. Mr. Wynn used many heat treating and tempering chart-slides to illustrate the versatility of the low-hydrogen electrode deposits to respond to various heat treatments which resemble the response of many aircraft medium alloy steels, particularly SAE 4130.

In answer to some questions Mr. Wynn advised as follows:

In so far there is no difference between ac and dc for welding with low-hydrogen electrodes, better physical properties are obtained from alternating-current electrode deposition. Apparently the fluctuating voltage and current develops continuous heating and quenching which in turn develops grain refinement in the weld.

It is necessary to have drying ovens for low-hydrogen electrodes with the present type of coating; 700° F is not high enough. Recent tests have shown that 1200° F is most effective in breaking down the absorbed moisture. In the future a ceramic coated electrode will be marketed.

This type of coating will eliminate costly drying operations.

In so far as low-hydrogen coating having any effect on most hard-facing applications, hard-facing alloys contained in the cellulose type of coating cannot be transferred (uniformly) across an arc. The coating must be of an inorganic type (L.H.).

Dick Hayes, program chairman, reported that the panel has a definite program layed out for the following months:

November—"Micro Spot Welding" by Ludwick Kellerman AWS, Victor Equipment Co., and Len Louett, Raytheon Co.

December—Christmas Party.

January—"Fusion Welding" by Francis Stevenson AWS, Aerojet Corp.

February—"Aircraft Silver-Alloy Brazing" by John Russ, Handy & Harman.

Dinner was held at Swally's Cafe in Los Angeles preceding the meeting at 8:00 P.M. for a group of 52. 54 attended the technical meeting.

Mechanized Welding

Louisville, Ky.—The October 27th dinner meeting of the *Louisville* Section, held at Korfage's Tavern was well attended. Cecil C. Peck AWS, president of the Cecil C. Peck Co., Cleveland, Ohio, spoke on the subject of "Tooling for Mechanized Welding." Mr. Peck, who has a number of installations of his company's equipment in Louisville, illustrated with slides various types of mechanized equipment that his company has built over the years for automatic welding. Some very complicated installations such as welding the bottom in a square tank were illustrated and described.

Bronze Electrodes and Filler Rods

Minneapolis, Minn.—The October meeting of the *Northwest* Section was held on Monday, October 12th, with R. E. Garriott AWS, Manager of Welding Rod and Wire Department, Ampco Metal, Inc., Milwaukee, Wis., as the speaker. Mr. Garriott spoke on "Jobs You Can Do with Bronze Electrodes and Filler Rods." This was a very interesting talk, illustrated with slides. The "Happy Half Hour" preceding the meeting was sponsored by Kenny Boiler & Mfg. Co., St. Paul, Minn.

Chairman Hanson also presided at the November meeting held on the 9th. The scheduled speaker, Lew Gilbert AWS Executive Editor, *Industry and Welding*, was unable to attend due to an airline strike. A question-and-answer program was organized with Russ Schleuder acting as moderator. The panel of experts consisted of Mr. Demmer, Air Reduction Sales Co.; Dr. Scott, Marquette Manufacturing Co; Mr. Williams, Lincoln Electric Co.; Mr. Palmer, Twin City Welding & Mfg. Co.; Mr. Benjamin, Great Northern Railroad; and Mr. Clogston and Mr. Underwood of Northern Ordnance, Ind. In spite of rather hasty organization of the meeting, it went off very successfully. The sponsor of the "Happy Half Hour" was the St. Paul Structural Steel Co. of St Paul.

Meeting Programs

Newark, N. J.—The *New Jersey* Section announces the following programs for the remainder of the current year:

January—E. V. Farrar, Assistant Chief Engineer, Wright Aeronautical Division, Curtiss Wright Corp., Subject: Jet Engines.

February—George Leonard, Metallurgical Engineer, American Rolling Mills, Baltimore, Md. Subject: The Welding of Stainless Steels.

March—R. F. Helmkamp, Air Reduction Sales Co., New York City. Subject: Cutting Machines and Cutting Procedures.

April—Edward Davis, Westinghouse Electric Corp., East Pittsburgh, Pa. Subject: Welding and Joining of Small Parts.

May—Blind Date.

Multiple Electrode Welding

Newark, N. J.—The November dinner meeting of the *New Jersey* Section was held at the Essex House on November 17th with an attendance of 86 members and guests.

Immediately following dinner, a film entitled "Time" and depicting a motor trip through the Grand Canyon area was shown. It was an above-average color and sound film furnished by the Ford Motor Co.

The guest speaker was Donald E. Knight AWS Unionmelt Development Engineer, Linde Air Products Co., Newark, N. J. His talk was entitled "Multiple Electrode Welding by the Submerged Arc Process." Using slides, the speaker outlined the correct nomenclature, defined the several current or power combinations which have been used successfully, and then discussed each of the combinations in detail from the standpoint of weld characteristics and applications. Mr. Knight's talk elicited a wide diversity of questions from his hearers.

The usual "After Meeting Snack" afforded an opportunity for further discussion and the usual amenities.

Jet Engine Alloys

New York, N. Y.—"Welding of Jet Engine Alloys" was the subject of a paper presented to the *New York* Section on November 10th. P. Gordon Parks AWS Chief Welding Engineer, Solar Aircraft Co., Des Moines, Iowa, was the speaker. Mr. Parks outlined the rapid development of the turbo-jet engine and discussed the problems encountered in the welding of the components of these power plants. An interesting series of slides showed how the Solar Aircraft Co. welds many of the "hot" parts used in these jet engines and pictured the jigs, fixtures and tooling for welding these components.

After presentation of the paper, the audience kept Mr. Parks engaged answering questions until a halt had to be called due to the lateness of the hour.

The meeting was held at Schwartz's Restaurant, 54 Broad St., where dinner was served prior to the technical session. E. W. Moles, Chairman of the Program Committee served as Technical Chairman.

Two door prizes were donated to the Section through the kindness of J. P. H. Wasserman of the Societe des Soudures Castolin S.A., Lausanne, Switzerland, who was the honored guest at the October meeting. These prizes were won by E. W. Moles and A. N. Sherwood, both members of the New York Section.

History of Welding

Oklahoma City, Okla.—Ray Townsend AWS of the Tweco Products Co. was the

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- ALLOY STEELS
- ALUMINUM
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- SPECIAL ALLOYS

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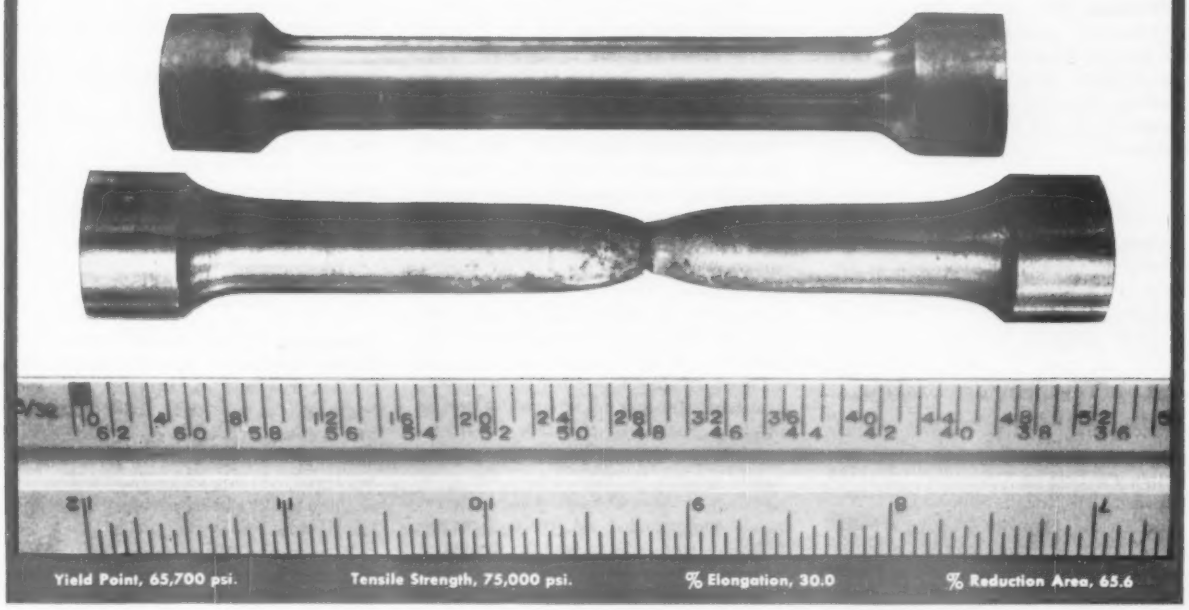
SW-65

Bar No. 4512-1
¼" electrode
on D.C. Reverse
As Welded



Outstanding physicals recommend the A. O. Smith SW-65

low-hydrogen electrode

Here is a picture of an all weld metal .505 of the A. O. Smith SW-65 low-hydrogen electrode. Remarkable strength, superior ductility and exceptional elongation put this electrode in a class by itself.

Nominally an E6016 electrode, it far exceeds A.W.S. specifications for this class. It is used in many applications as an E7016 because of its superior physicals.

Its better manipulation, lack of spatter, easy re-strike, quick cleaning slag and fine appearing bead make it an operator's favorite from the very first trial.

With SW-65, you have the exceptional electrode for welding cold-rolled steel, re-rolled rail, high carbon, sulphur, selenium bearing steels and steels of poor weldability.

This is the electrode to use with confidence whenever there is any doubt about weldability, and where you desire high physical and x-ray quality.

May we suggest that you write us or contact your local A. O. Smith distributor for full details and a chance to test this remarkable low-hydrogen electrode.

A.O.Smith
CORPORATION

WELDING PRODUCTS DIVISION, MILWAUKEE 1, WISCONSIN
INTERNATIONAL DIVISION: MILWAUKEE 1, WISCONSIN

speaker at the September 22nd meeting of the *Oklahoma City* Section. His subject, "The History of Welding," was well received by the 80 people present.

Plant Visit

Oklahoma City, Okla.—One hundred and twenty-five members of the *Oklahoma City* Section and guests made a tour of the plant of Black, Sivalls & Bryson, Inc., on Tuesday, October 29th. Ninety were present for the Air Power movies and refreshments.

Glass Industry

Olean, N. Y.—Howard Baker of the Pittsburgh Corning Plant gave a detailed talk on the glass industry in Port Allegany at the October 27th meeting of the *Olean-Bradford* Section.

Low Temperature Brazing

Pascagoula, Miss.—The regular monthly dinner meeting of the *Pascagoula* Section was held on November 11th at the Shipyard Cafe, Ingalls Shipyard.

Mr. Thomas Dawson, AWS gave a résumé of the activities which took place during the National Fall Meeting held in Cleveland.

Featured speaker of the evening was Charles Brown, AWS, Southern Division Manager, Eutectic Welding Alloys Corp., who presented a semi-technical discussion on the subject "Low Temperature Brazing." Mr. Brown's talk was illustrated with motion pictures.

Jet Engine Components

Philadelphia, Pa.—The *Philadelphia* Section met for their regular technical meeting on November 16th, and were honored to have as guest speaker for the evening Arnold Rose of the Special Products Division of I-T-E Circuit Breaker Co. Mr. Rose discussed in detail ways and means for welding Jet Engine component parts, all of which had been successfully welded by his company. Many of these applications were amply illustrated by slides which were furnished through the courtesy of the I-T-E Circuit Breaker Co.

Whether the speaker, Arnold Rose, or the subject "Welding of Jet Components" was responsible for the largest turnout of the year is still open to speculation, but the writer is of the opinion that both the speaker and his well chosen subject were responsible for the attendance of nearly 100 members and guests.

Prior to the Technical Session, a dinner meeting was held to honor the Past Chairmen of the Philadelphia Section. The attendance of approximately 70 members and guests at the dinner meeting makes it worthy of mention. Among the Past Chairmen present were R. D. Thomas, T. M. Jackson, H. W. Pierce, A. A. Holzbauer, L. T. D. Berg, O. C. Frederick, K. Wm. Ostrom and R. A. Guenzel. These leaders were introduced by the present Chairman, R. D. Bradway, and they were cited for their contributions to the Philadelphia Section. Other Past Chairmen sent their regrets that they were unable to attend this meeting due to pressing problems and traveling distances involved.

Management Views AWS

Portland, Ore.—The third meeting of the current season of the *Portland* Section was held on November 10th at the Heathman Hotel. As per previous agreement with the members, refreshments were served by the hotel on a "buy-as-you-want" basis. Also in accordance with the wishes of the membership, dinner was served at 7:00 rather than at 6:30 as in the past.

Guest speaker was Roy N. Bowman, Assistant Manager of Wilamette Iron & Steel in Portland. His talk "Management Views the AWS" was not only a timely subject for this, one of the early meetings of the season, but was of interest to all who attended. A lively discussion following the speaker's talk produced considerable interest.

The Portland Section is working on an Educational Program to be sponsored by the Section and open to all welders and those interested in welding in the area. It is hoped to have this worked out in the near future. No meeting was held in December, this year.

New Officers

Richmond, Va.—The following officers and Committee Chairmen have been appointed by the *Richmond* Section:

Chairman—Vaughan E. Calder, Jr. 5802 Richmond Ave., Richmond, Va.
First Vice-Chairman—W. B. Jones
Second Vice-Chairman—Charles G. Dillard
Secretary—W. Wayne Utley
Treasurer—Fred T. Mayers
Chairman, Membership Committee—George Watkins
Chairman, Program Committee—Raymond L. Thayer, Jr.
Technical Representative—Vaughan E. Calder, Jr.

Inert Arc Welding

Rochester, N. Y.—The first event of the 1953–54 program of the *Rochester* Section was a plant visitation at the Pfaudler Co., one of the world's largest producers of glass-lined tanks. There were over 150 in attendance. After a welcome by E. E. Geisinger, Vice-President of Pfaudlers, the group was conducted through a very interesting plant tour including all the latest in welding techniques.

The first meeting was held on Monday, Nov. 16, 1953, and the principal speaker was G. J. Gibson AWS, Research and Development Engineer, Air Reduction Sales Co., Murray Hill, N. J. His subject was "The Fundamentals and Versatility of the Inert Gas-Shielded Tungsten-Arc-Welding Process." After a very thorough talk Mr. Gibson answered many questions from the group. Preceding the main speaker was a short talk by Robert Perry, District Game Manager, State Conservation Department. His interesting talk was on "The Sportsman and the Landowner." Over 75 members and guests attended this meeting and, after a closing message from Chairman Clyde Martin, the meeting was adjourned.

Quiz Program

Saginaw, Mich.—The November 12th dinner meeting of the *Saginaw Valley* Section was held at the High Life Inn, Saginaw, Mich. Right after dinner a movie entitled "Buck Fever" was shown, a kick-off before deer season opened in Michigan. It sure seemed easy to bag one of those bucks and here's hoping everyone has good luck in getting theirs.

Jim Quigley AWS of Lincoln Electric Co. was chief moderator of the "Quiz Nite" program with a panel consisting of four experts: Jim Nichols, Fred Williams, Paul Thorne and Robert Woollard. A series of 20 questions were distributed to each member and guest. The questions covered resistance welding, inert arc welding, submerged arc welding, metallic arc welding and a few general questions. A welding handbook was awarded to Mr. Macauley, Jr., for answering the most questions correctly. Mr. Spice, Mr. Stanilus and Mr. Dell were all tied for first place with Mr. Macauley, Jr., but since all three already had a handbook they agreed to let Mr. Macauley take the award—a very nice gesture on their part. A booby prize was also awarded to the members who answered the least number of questions correctly.

Fellowship Meeting

St. Louis, Mo.—An Organization and Fellowship Meeting was held on October 9th by the *St. Louis* Section. The meeting was primarily concerned with presenting to the membership a plan suggested to the Section at the last District Meeting. This plan is that of setting up a system of Technical Panels on a Section basis. The Chairman pointed out that utilization of such a system should be of value to local industry, individual members of the Section and the Section itself. He explained that the first step would be to select an industry and consult with various companies in it, as to their mutual welding problems. Then, through the auspices of the Section, and with the tech-

nical assistance of the Section, various individuals in the same industry could be brought together to work out their mutual problems. The Chairman went on to explain that in this way some difficult welding problems might be resolved which would broaden the use of welding and promote membership in the AMERICAN WELDING SOCIETY.

Some of the Panels proposed were: Structural Fabrication, Pressure Vessel Fabrication, Pipe & Tubing Fabrication, Welding in the Railroad Industry, Welding Safety, Suppliers' Committee, Aircraft Welding, etc.

There was considerable discussion on this program, and later a vote was taken. All but three present were in favor of it. With this backing from the membership, the St. Louis Section plans to go ahead with this program.

After the meeting, two color sound films were shown entitled "Tarpon Fishing" and "Prairie Wings."

Panel Discussion

St. Louis, Mo.—The November 13th dinner meeting of the *St. Louis* Section was held at the Forest Park Hotel. Thirty-five were present. The talk by the Coffee Speaker on Civil Defense in St. Louis by Martin Kaercher, Commander of Auxiliary Police, was very enlightening and interesting. Mr. Kaercher explained how the Auxiliary Police is organized to help in any emergency, atomic or otherwise. At the conclusion of this talk, one of the members proposed that the services of the Section be offered to the Auxiliary Police, since welding and oxy-acetylene cutting is very important in disaster and rescue work. Mr. Kaercher said that he felt this was an excellent idea, and is investigating the feasibility of such a plan.

The Panel Discussion was very animated. All questions came from the floor, and it was not necessary for the Panel members to introduce any questions themselves. Several phases of welding and heat treating armor plate were discussed. There was also a discussion of welding of freight car parts, and another on the cures for arc blow due to magnetized material. It appeared that all those present enjoyed this discussion very much.

Panel members were Phillip H. Smith, Nooter Corp., Moderator; John Patton, General Steel Castings Corp.; Russell A. Royer, Midwest Pipe & Supply Co.; and Bernard J. Brugge, Lincoln Electric Co.

High-Temperature Alloys

Salt Lake City, Utah—The September 17th dinner meeting of the *Salt Lake City* Section was held at the Hotel Temple Square. Charles Hopkins of Linde Air Products Co. described the "Welding of High-Temperature Alloys."

Plant Tour

Salt Lake City, Utah.—A tour of the plant of the Salt Lake Refining Co. was made by 25 members to the *Salt Lake City* Section on October 15th.

A-C Versus D-C Welding

Salt Lake City, Utah.—Ed Bartz AWS, Pacific Coast Welding Supervisor, Westinghouse Electric Corp., San Francisco, Calif., was the guest speaker at the November 19th meeting of the *Salt Lake City* Section. Mr. Bartz' nontechnical talk was on the subject "A-C Versus D-C Welding."

Job Shop Welder

Seattle, Wash.—William E. Snider, AWS of Webster Welding, Seattle, Wash., described the "Woes of a Job Shop Welder at the November 12th dinner meeting of the *Puget Sound* Section held at the Engineers Club. This excellent extemporaneous talk was of general interest to all of the 47 members attending the meeting.

C. M. Styer AWS of the Pacific Car and Foundry Co. gave a detailed report on the National Fall Meeting, recently held in Cleveland.

A 16-mm sound color film entitled "How a Corporation Can Be Started Selling Capital Stock" was shown through the courtesy of the National Cylinder Gas Co.

Heliarc Welding

Sheffield, Ala.—The November 20th meeting of the *Tri-Cities* Section was held in the TVA Auditorium. An excellent discussion on heliarc welding was given by Frank Crowson of Linde Air Products Co., Birmingham, Ala.

A sound color film entitled "Greentree Thoroughbred" was shown through the courtesy of movies, U. S. A.

Resistance Welding

South Bend, Ind.—A showing of the General Electric film, "This Is Resistance Welding," preceded a talk on this subject by F. A. Bodenheim, Jr., AWS, Sales Manager for Welders for the Federal Machine and Welder Co., Warren, Ohio, at the *Michiana* Section held on November 19th. Leaving the film to take care of the basic principles of the resistance welding process, Mr. Bodenheim stressed the economies that are possible, especially if automation can be applied. By means of slides and some other movies, he showed many examples of machines that have been designed to use projection and spot welding to their best advantage. The movies were taken to show the cycle time factor A clock with a sweep second hand was incorporated in every view, so that the timing of each phase of machine operation could be ascertained. This was especially significant in evaluating fast-moving operations.

Inert Arc Welding

Springfield, Ill.—The November 10th dinner meeting of the *Sangamon Valley* Section was held at the Mill Tavern. T. W. Eselgroth of Linde Air Products Co. brought the members up to date on "New Developments in Heliarc and Sigma Welding."

Welding Aluminum Alloys

Syracuse, N. Y.—Approximately 110 members and guests attended the November 11th meeting of the *Syracuse* Section held in the Hiawatha Room of the Hotel Onondaga. The subject of the meeting, "Welding Aluminum and Its Alloys" was presented by Charles Bruno, AWS, Chief Welding Engineer, Reynolds Metals Co., Louisville, Ky. Mr. Bruno presented data on fusion and resistance welding procedures for all weldable grades of this important engineering material. Recent research developments in aluminum welding were also discussed.

I. Morrison, AWS, Director at Large and Clarence Jackson, AWS, District Vice-President, were guests at this meeting. At a special Board Meeting held before the technical session, these officers outlined the proposed district program aimed at closer intersectional cooperation.

Distortion Control

Toledo, Ohio.—Jack Roscoe AWS, of the Lincoln Electric Co., Cleveland, Ohio, gave a semitechnical talk on "Control of Distortion"at the November 10th meeting of the *Toledo* Section held at VFW Post 606.

John H. Blakenbuehler, Vice-President, District No. 4, was present for the dinner and meeting and said a few words of interest to all.

A social get together and refreshments took place after the meeting.

Movie

Tucson, Ariz.—The *Tucson* Section held its second meeting of the fall season on October 20th at the club house of the Tucson Municipal Golf Course. The meeting was preceded by dinner with 30 members attending the technical meeting.

After dinner, a movie "The Magic Wand" by Lincoln Electric Co. was shown and then the program consisted of a panel of five members of the Section who each gave a 10-minute talk on welding in their particular line of work. After these talks were concluded, Geo. Hunt, Section Secretary, conducted a lively question-and-answer period regarding the previous

talks. The members participating in this program were: W. H. Barnier, Charles Condron, Dewey White, Geo. Kushmaul and Cliff Stahl. Their subjects were: Job Shop Welding, Heavy Equipment, Maintenance Welding, Pipe Line Maintenance Welding, Machine Shop Welding and Automatic Welding.

Welding Aluminum

Tucson, Ariz.—The *Tucson* Section held its regular meeting on November 17th at the Tucson Municipal Golf Course Club House.

Speaker for the meeting was Charles Bruno, AWS, Chief Welding Engineer Reynolds Metals Co., Louisville, Ky. Mr. Bruno's subject "Welding Aluminum" was presented with the aid of charts and pictures and was the most interesting talk that the local section has had. Mr. Bruno held a discussion period after his prepared lecture which lasted an hour after the regular meeting adjourned. Everyone present agreed that Mr. Bruno was exceptionally good, and made a wonderful presentation of his subject.

Meeting Programs

Washington, D. C.—The meetings of the *Washington* Section are held at Pepco, 10th & E Sts., N. W., and start at 8:00 P.M. Following are the dates and subjects of these meetings for the remainder of the season:

January 27th—Educational Meeting "Training and Advanced Information for Brazing Operators," E. F. Davis, Westinghouse Electric Corp., Pittsburgh, Pa. "Maintenance Welding," T. B. Jefferson, Welding Engineer, Chicago, Ill.

February 24th—"Movie Night"—Technical, unusual and possibly a Mickey Mouse

March 31st—"Recent Developments in the Inert Gas Consumable Metallic Arc Welding Process," J. Berryman, Air Reduction, Inc., Murray Hill, N.J.

April—Annual Banquet. Place and location will be announced later.

Old Timer's Night

West Springfield, Mass.—An Old Timers' Night meeting was held on October 13th by the *Western Massachusetts* Section. The program consisted of an introduction of a review of early welding methods, equipment and applications. A general discussion period followed.

Season Program

West Springfield, Mass.—Following are the meeting dates and subjects for the remainder of the season of the *Western Massachusetts* Section:

Jan. 12, 1954—Tool and Die Welding
Feb. 9, 1954—Safety Program
Mar. 9, 1953—Resistance Welding
Apr. 13, 1954—Discussion: Panel of Experts in Three Selected Fields

Welding Stainless Steels

Worcester, Mass.—Lorin K. Poole AWS, of the Arcos Corp., Philadelphia, presented a highly technical paper on "The Welding of Stainless Steels" at the October 5th dinner meeting of the *Worcester* Section held at the Tower House.

Resistance Welding

Youngstown, Ohio.—J. H. Cooper AWS of the Taylor-Winfield Corp. gave an excellent extemporaneous talk on the subject "Resistance Welding" at the October 15th dinner meeting of the *Mahoning Valley* Section held at the El Rio Restaurant with an attendance of 45.

Tinning

Youngstown, Ohio.—The November 19th dinner meeting of the *Mahoning Valley* Section held at the Mahoning Country Club, Girard, Ohio, was addressed by D. A. McArthur, Chief Engineer, The Wean Engineering Co., Inc., Warren, Ohio. Mr. McArthur presented an excellent semitechnical address on "Electrolytic Tinning."

LIST OF NEW MEMBERS

Effective October 31, 1953

Membership Classification

A—Sustaining Nember
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

ANTHONY WAYNE

Garman, Ray G. (B)

ARIZONA

Dye, Gil V., Jr. (C)
Newhouse, Earl W. (C)

BIRMINGHAM

Jones, Robert Lee (B)
Neville, N. L. (B)

BOSTON

Bakerman, Harry (B)
Barilaro, Albert R. (C)
Brackett, David H. (C)
Burridge, Henry Fredrick (C)
Gillum, Warren S. (C)
Long, James T. (B)
Ostrov, Harold (B)
Schradieck, Richard H. (B)

CANADA

Bennett, Harry Gordon (B)
Newby, George R. (B)

CHATTANOOGA

McClanahan, John J. (C)

CHICAGO

Bodecker, Wurdell R. (B)
Cooper, James M. (C)
Flor, H. C. (C)
Langhenry, Edward (B)
Leahy, John (B)
Mikulka, Frank M. (B)
Schumacher, William G. (C)
Wigley, C. M. (C)

CINCINNATI

Lynn, Gilbert H. (C)
Walton John T. (C)

CLEVELAND

Bennett, Frank M. (B)
Bennett, Frank S. (B)
Clipsham, Robert B. (C)
Davies, Floyd (B)
Morgan, C. P. (B)
Moss, Victor M. (C)
Shepherd, William V. (C)
Wojcik, Stanley W. (C)

COLORADO

Kern, Frederic G. (C)
Probst, Vincent G. (C)

COLUMBUS

Gross, Arthur F. (B)
Spielberg, Nathan (B)

DAYTON

Bercaw, Donald (C)
Corbet, Roy (C)
Hammarstrom, John V. (C)
Hanson, Raymond A. (C)
Thomas, Paul D. (C)

DETROIT

Ball, Daniel (B)
Boretti, Napoleon P. (C)
Bryant, C. Brate (B)
Byrd, Fred M. (B)
Kinnear, Joseph D. (B)
Macewka, John (B)
Perry, Russell (B)
Pretti-Pavletta, Jerry A. (C)
Saffady, Tom (B)
Targosz, Stanley J. (C)
White, Calvin (B)

HARTFORD

Andreano, Guido Andrew (B)

HOUSTON

Fickel, M. L. (C)
Grebe, Arthur B. (B)
James, W. L., Jr. (C)
Lisenbee, R. G. (B)
Reese, Earle B. (B)
Talley, R. R. (C)
Wood, Jean Stephen (B)

IOWA-ILLINOIS

Hill, Glenn U. (C)
Wilson, Jerome J. (C)

KANSAS CITY

Goldsmith, John M. (B)

LEHIGH VALLEY

Brubaker, Enos H., Jr. (C)
Gross, John Hammes (C)
Roberts, Leonard (C)

LONG BEACH

Gaskill, Robert E. (B)
Smithey, William C. (B)
Wood, Melvin M. (C)

LOS ANGELES

Annear, Reed B. (B)
Boisver, Lawrence R. (B)
Coran, Donald E. (B)
Gearhart, William E. (C)
Patterson, Thomas James (C)
Pearson, Marvin D. (C)

MAHONING VALLEY

Charlton, Robert E., Sr. (B)

MARYLAND

Blome, George S., Jr. (B)
Fisher, Donald H. (B)
Wilburt, George A. (B)

MICHIANA

Quimby, Orlie (C)

MILWAUKEE

Couch, Harold E. (C)
Manning, Daniel F. (C)
Revall, Richard (C)
Rolling, Donald C. (C)
Sidbeck, Paul (B)
St. Vincent, Fred (B)
Wiggins, Earl (C)

NEW JERSEY

Brocke, Edward C. (B)
Derechin, Seymour (B)
Lindsay, Ian Cameron (B)
O'Connell, Paul B. (B)
Perry, Gordon K. (C)

NEW YORK

Alessandria, Angelo V. (B)
Davis, George M. (C)
Ericson, Valentine (B)
Gans, Howard M. (C)
Gracer, Martin M. (B)
Olin, Warren G. (B)
Thomas, P. D. (B)

NIAGARA FRONTIER

McCandless, E. L. (C)
Newman, Arthur J. (C)

NORTHEAST TENNESSEE

Dempster, Thomas C., Jr. (B)
Wheeler, George Smith (B)

NORTHERN NEW YORK

Garvey, Edwin (C)
Moazed, Khosrow Louis (D)
Parker, Frank S. (C)

NORTHWEST

Gustafson, Phillip E. (C)

OLEAN-BRADFORD

Robinson, Michael Hall (B)

PASCAGOULA

Calhoon, Jack R. (C)
Campbell, Joseph A. (C)
Germany, Tom R. (C)
Hall, L. A. (C)
Lawhon, W. R. (C)
Valentine, Fred (C)

PEORIA

Hundley, Arthur A. (C)
Richardson, Lawrence (C)
Schlis, Art (C)

PHILADELPHIA

Dentino, Thomas C. (C)
Dorschu, Karl E. (B)
Estel, George A., Jr. (B)
Gaul, Alfred H. (C)
Gessner, Herman K. (C)
Harris, Jack W. (C)
Musi, Vincent J. (B)
Smith, Everett (C)
Smith, Irwin S., Jr. (B)

PITTSBURGH

Baker, Charles P., Jr. (C)
Bennone, James O. (B)
Cameron, M. B. (B)
Griffith, Harry W. (B)
Hoffmann, William F. (B)
Valetti, Louis F. (B)

PUGET SOUND

Gibbs, F. Eugene (C)
Hayes, William E. (C)
Messer, Elwin (B)
Sheaffer, Charles (B)
Slosson, Stiles R. (C)
Thorpe, Don H. (C)

RICHMOND

Brown, Meyer (B)

ROCHESTER

Kenney, Malachi P. (B)

SAGINAW VALLEY

Berryhill, John D. (C)
Black, Bruce (D)
Boyer, Robert H. (D)
Cook, Jack Eugene (D)
Enderby, Donald (D)
Friermood, Eugene L. (D)
Glaze, Richard F. (D)
Gray, William S., Jr. (D)
Heintzelman, Kermit N. (D)
Kennedy, John P., Jr. (D)
Steele, Guy (D)
Walsey, Harvey (C)

ST. LOUIS

Mullen, Roy F. (C)

SALT LAKE CITY

Leonard, Howard R. (C)

SAN FRANCISCO

Chapman, Robert F. (C)
Olds, Edwin (B)
Rowen, Donald K. (B)
Valentine, Joel (B)

SANGAMON VALLEY

Hansen, John T. (B)

SYRACUSE

Gagnon, Thomas E. (C)
Hill, Robert L. (C)
Hilton, James C. (C)
Hoefer, Earl (C)
Schaefer, Myron Joseph (B)
Solberg, Richard C. (C)

TRI-CITIES

Shields, Trewhitt H. (B)

TUCSON

Denn, Albert (B)

TULSA

Bard, J. A. (B)
Brown, Raymond C. (C)
Iddings, C. D. (B)
McKenzie, Ben F. (C)
Pannell, Leon (C)
Reed, Paul S. (B)
Reed, William Herbert (B)

WESTERN MICHIGAN

Cleveland, Darrell C. (B)
Edgerle, Thomas E. (C)
Hand, Ray B. (B)
Ignatoski, Adam J. (C)
Miedzielec, Edward J. (C)
Miller, James C. (C)
Miller, Joseph A. (C)
Perkins, Gerald A. (C)
Richards, Kenneth D. (C)
Thayer, Floyd H. (C)
Wiernega, Ernest (C)
Wyngarden, Donald (B)

WORCESTER

How, Edward K. (B)
Rennie, Robert M. (C)

YORK-CENTRAL PENNSYLVANIA

Sill, Albert, Jr. (C)

NOT IN SECTIONS

Llorens, Sergio Mohar (B)
McIlhaney, Truman H. (B)

Members Reclassified

During the month of November

LOS ANGELES

Wynn, Arthur R. (C to B)

MARYLAND

McPherson, M. E. (C to B)

PASCAGOULA

Moore, Vincent E. (C to B)

PHILADELPHIA

Aarts, Cornelius (C to B)
English, Laurence P. (C to B)

SAN FRANCISCO

Quist, Ralph H. (D to C)

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prepared by V. L. Oldham

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2,657,298—Method and Apparatus for Manufacturing Composite Plates—Orrin E. Andrus, Milwaukee, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

This patent relates to bonding two members together when they are disposed in contiguous flatwise relation. The new method comprises inductively heating opposed portions of the members to a bonding temperature and applying high fluid pressure to the outer surface of at least one of the portions. This portion is bent by the fluid pressure to conform with the opposed portions of the other member as distinguished from being deformed into conformity with such opposed portions.

2,657,650—Torch for Cutting Stainless Steel—Alfred F. Chouinard and John B. LaPota, Chicago, Ill., assignors to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

This patented cutting torch has a cutting tip provided with a central high-pressure oxygen passage and an annular row of passages for combustible gaseous mixtures. A sleeve encircles the delivery end portion of the tip and has an annular row of converging discharging passages. Other means require a staggered positioning of the passages of the two annular rows.

2,657,660—Apparatus for Open Butt Welding Metal Workpieces—John J. Crowe, Westfield, N.J., assignor to Air Reduction Co., Inc., a corporation of New York.

Crowe's patented apparatus includes a pair of work supports mounted for relative movement toward and away from each other for bringing the work faces of the workpieces into abutting relation. A pair of gas heating torches are positioned in the apparatus with one torch holder positioning its torch to extend diagonally downwardly against one of the work faces and the other torch directs its heating flames diagonally upwardly against the other of the work faces. Movement of the work supports toward each other swings the torch holders and maintains them so as to cause the torch tips to direct the heating flames diagonally against the work faces until they are brought into abutting relation.

2,658,132—Remote-Control System for Direct Current Welding—Claude A. Welch, Cincinnati, Ohio, assignor to Welch Electric Co., Inc., Cincinnati, Ohio, a corporation of Ohio.

A system for remotely controlling the output of a d-c welding generator that supplies current to a pair of welding electrodes is disclosed in this patent. The control system includes a circuit for supplying rectified a-c energy to the generator field, which circuit includes a saturable reactor for controlling the a-c input to the rectifier means in the circuit. A further control is provided that includes a control winding on the saturable reactor and a variable resistance so that variation of the resistance results in control of the energy supplied to the control winding and adjustment of the a-c input to the rectifier and consequent adjustment of the input to the generator field.

2,658,133—Electrode Holder—James R. Barrow, Columbiana, Ohio, assignor to Columbiana Boiler Co., Columbiana, Ohio, a corporation of Ohio.

The electrode holder disclosed in this patent includes a pair of parallel, elongated jaws pivotally secured together. Electrical energy is supplied to the electrode holder at the jaws thereof to prevent any undue heating of portions of the holder other than the jaws.

2,658,162—Welding Apparatus—Edwin L. Tichenor, Clifton, and William F. Cremins, Montclair, N. J., assignors to Curtiss-Wright Corp., a corporation of Delaware.

This patent relates to an automatic electric welding setup including a welding head having a welding rod feed roll including annular grooves spaced apart a short distance and means for driving the feed roll to feed welding rods engaged with the roll in a unitary manner. A unitary welding rod guide and nozzle member of electrically conductive material is secured to the welding head in insulated relation thereto. An insulating guide sleeve embraces each weld rod and is disposed between the feed roll and the member. Weld rods engage the feed roll and pass through the sleeves and contact the weld rod guide and nozzle member for welding current transfer thereto. Conductor means connect to the guide and nozzle member for transmitting welding current thereto.

2,658,548—Formation of Welding Projections on Tubes—Charles W. Harrison, Warsaw, Ind., assignor to Arnolt Corp., Warsaw, Ind., a corporation of Indiana.

Harrison's patent relates to specialized apparatus of the character indicated in the patent title.

2,658,981—Welding Beryllium and Beryllium Alloys—David C. Martin, Worthington, Ohio, assignor to the United States of America as represented by the United States Atomic Energy Commission.

The novel welding process of this patent relates to the welding of beryllium-base metals and the process comprises welding the metals using a shield gas consisting of from 90 to 99.5% by volume of a noble gas and from 5 to 0.5% by volume of a fluorochlorohydrocarbon. Such a substance is selected from the group consisting of fluorochloromethanes and fluorochloroethanes.

2,659,036—Alternating Current Arc Welding Equipment—James Christopher Needham and Leonard Herbert Humphrey Orton, Greenford, England, assignors to E. R. A. Patents Ltd.

This patent relates to an alternating-current arc-welding system wherein a pair of arc-welding electrodes are connected to a source of alternating current, while a source of direct current is also present in the system. A normally open circuit extends between the source of direct current and the arc for applying across the electrodes a unidirectional current pulse of a voltage of less than 500 v. A switching device responsive to the condition of the arc across said electrodes closes for passage of a current pulse when the arc commences to extinguish.

2,659,138—Method of Brazing and Brazing Alloy—Philip T. Stroup, New Kensington, Pa., assignor to Aluminum Company of America, Pittsburgh, Pa., a corporation of Pennsylvania.

A new brazing alloy is disclosed in the patent and is composed of silicon, germanium and aluminum. The alloy contains

not more than about 0.5% by weight of other metal. The percentage of silicon by weight is about equal to 11.5 minus X and the percentage of germanium by weight is about equal to $4.5X$ where X represents a number not less than 1 nor greater than about 10.5.

2,659,332—Welding Jig for Repairing Plowshares—Lee O. Wiese, Perry, Iowa.

A specialized welding jig is covered in this patent.

2,659,796—Electric Welding Apparatus—Nelson E. Anderson, Berkeley Heights, N. J., assignor to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

This patent relates to gas-shielded arc-welding apparatus for use with long lengths of clean flexible aluminum electrode wire. The apparatus includes a manual gun containing an inner wire guide assembly, and a welding current contact member nearer the welding arc than the wire guide assembly. A surrounding outer-gas-conducting shield-forming assembly is provided, and a flexible casing assembly is connected to the rear of the gun to convey welding wire to the gun. The casing has an internal surface of nylon, and power-driven wire-feed means are provided for continuously pushing the electrode wire through the casing, wire guide and contact element to the welding arc.

2,659,797—Arc Welding Apparatus—Nelson E. Anderson, Berkeley Heights, and Edmund T. Sullivan, Laurence Harbor, N. J., assignors to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

Arc-welding apparatus is covered in the patent and includes a tubular structure and means for retaining an electrode in coaxial relation with the tubular structure with the end of the electrode projecting out of the lower end thereof. A nozzle-holding sleeve surrounds the lower end of the tubular structure and forms therewith an annular water chamber. Special seal means are provided for securing the nozzle-holding sleeve in the tubular structure.

News of the Industry

(*Continued from page 78*)

permanent collaboration of the delegates of the various countries on the Documentation Commission of the International Institute of Welding makes possible the preparation of this bibliographical review. It is edited, translated and published by the French Institute of Welding.

The *Bibliographical Bulletin for Welding* is published in two languages: one side of the pages is in French and the other in English, thus making it possible to keep a card index of the bibliographical abstracts in either language. The abstracts are classified in accordance with a specially devised system which is particularly adapted to welding documentation; the principles of the scheme can be rapidly learned from the classification table.

The annual subscription (four quarterly numbers containing more than 2300 abstracts) is 4800 French francs; this subscription is reduced for the members of member societies of the International Institute of Welding to 3250 French francs.

Each new subscriber receives free of charge a copy of the classified table.

Subscriptions may be taken out direct from the publisher: Les Publications de la Soudure Autogene, 39, rue d'Amsterdam, Paris 8e.

Multi-Lingual Terminology of the I.I.W.

The first section, "Gas Welding," in ten languages, of the *Multi-Lingual Terminology for Welding and Allied Processes* appeared during 1953.

This section is the first of a series which will cover the whole field of welding and allied processes. It is a particularly authoritative work, having been prepared by Commission 6 of the IIW which is composed of experts in terminology from all the countries whose languages are included in the Lexicon—the most complete in existence on gas welding.

This section comprises terms specifically dealing with the gas welding process in ten languages: Danish, Dutch, English, Finnish, French, German, Italian, Norwegian, Spanish, Swedish. The number of terms included is about 350.

The Lexicon comprises a complete list of the terms in ten languages, the terms being listed in logical order. In this list each term is numbered, the number being the same whatever the language. This logical list is subdivided into chapters in order to facilitate finding any term sought.

In addition, there is an alphabetical list for each language, in which each term is followed by its number in the list of terms in their logical order.

This publication may be ordered either from the IIW or from the publisher: Société suisse de l'Acetylène, 95, St. Albanvorstadt, Basle.

Collection of Reference Radiographs for Welds

An international collection of 50 radiographs showing examples of typical welding defects, graduated in importance, appeared during 1953. This collection was prepared by a Subcommission of Commission 5—Testing, Measurement and Inspection of Welds. It is intended to assemble a larger collection, of which the present collection will be the first section. This section covers arc welds of steel from 10 to 30 mm thick. The radiographs are framed in cardboard cards on which are given, in French on one side and in English on the other all relevant technical details. On the edge of the card is a perforation corresponding to each detail given. This arrangement makes it possible to remove in a few seconds all the cards corresponding to a given defect and showing a weld carried out under given conditions, taking into consideration the welding conditions.

The cards are in five colors, according to the importance of the defect shown in the radiograph which they frame: black (sound weld), blue, green, orange, red (very bad weld).

The selling prices of this section are as follows: to members of the IIW the film edition is 165 Swedish Crowns while the paper edition is 125 Swedish Crowns; to nonmembers of the IIW the film edition is 200 Swedish Crowns and the paper edition is 150 Swedish Crowns.

Orders should be placed through, Tekniska Röntgencentralen, Experimental faltet, Stockholm, Sweden, which is acting as Central Office for this purpose.

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INDEX TO ADVERTISERS

Air Reduction ..... Outside back cover
American Chain and Cable 72
American Welding Society 70
Ampco Metal, Inc. 82
Arcos Corporation 62, 63
Armour Research Foundation 78
Aronson Machine Co. 60

Battelle Memorial Institute 78
Becker Brothers Carbon Co. 66

J. W. Dice Co. 76
Diversey Corporation 96

General Electric 80, 81

Haynes Stellite Company, a Division of Union Carbide and Carbon Corporation 61
Hobart Brothers Company 1

The International Nickel Company, Inc. 6

Jackson Products ..... Inside back cover

Lapeer Mfg. Co. 66

The Lincoln Electric Company 67
Linde Air Products Company, a Division of Union Carbide and Carbon Corporation 4

P. R. Mallory & Co., Inc. 3
Metal & Thermit Corporation 2

National Carbide Company 58
National Welding Equipment Co. 59

Page Steel and Wire Division 72

Sciaky Bros. 65
Square D Company 77
Stulz-Sickles Co. 68
A. O. Smith 89
Smith Welding Equipment Corp. 83
Sylvania Electric Products, Inc. 69

Tempil® Corporation 85
Tweco Products Company ..... Inside front cover

Union Carbide and Carbon Corporation
Haynes Stellite Company 61
Linde Air Products Company 4
United States Testing Company, Inc. 84

Welding Fittings Corp. 73
Weldwire Company, Inc. 88

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Supplement to the Welding Journal, January 1954

Optimum Spot and Seam Welding Conditions for Inconel X

Effect of properties of Inconel X in spot and seam welding and determination of optimum conditions on the basis of tension-shear, cross-tension and pillow tests

by Ernest F. Nippes and Herbert B. Fishman

Abstract

This research covers the determination of the optimum spot and seam welding conditions for 0.010-, 0.015-, 0.021-, 0.031- and 0.062-in. Inconel-X sheet. Inconel X is a precipitation-hardening alloy for high-temperature use. The unique properties of Inconel X and their effect upon spot and seam welding are discussed. The procedure for the determination of the optimum conditions is outlined from the standpoint of the limits imposed upon the welding variables by the RWMA criteria for spot and seam welding. These criteria are explained and the interrelation of variables is discussed. The results of tension-shear and cross-tension tests for spot welds are shown and discussed. The pillow test was used for determination of the rupture strength of pressure-tight seam welds. The maximum rupture strength was found to be a linear function of sheet thickness. Since sufficient force was not obtainable with the available seam welding equipment, the optimum values for seam welding of 0.062-in. Inconel X could not be found. However, the effects of insufficient weld force are discussed.

INTRODUCTION

MEMBERS of the research staff of the Rensselaer Polytechnic Institute Welding Laboratory have been engaged in the determination of optimum resistance-welding conditions of nickel and high-nickel alloys since 1939. The program has been guided by its capacity to aid in the industrial fabrication of these materials. Previous phases of this project established the optimum spot,[1] flash,[2] cross-wire[3] and seam welding conditions for nickel, Inconel and Monel.[4] The International Nickel Co., Inc., has been sponsoring this research continuously up to the present date.

The aim of the research described in this report was the determination of the optimum spot and seam welding conditions for 0.010, 0.015, 0.021, 0.031 and 0.062 in. thicknesses of Inconel-X sheet. The optimum welding conditions were taken at the widest reproducible range giving results within the limits of the various criteria established by previous workers and the recommendations of the *Resistance Welding Manual* of the Resistance Welding Manufacturer's Assn. These resistance welding criteria are listed below:

1. No porosity or cracking in the fusion zone.
2. Less than 5% indentation or 10% sheet separation.
3. Fusion-zone penetration of 30–80% of the total sheet thickness.
4. 10–25% fusion-zone overlap for pressure-tight seam welds.
5. A wide and reproducible current range. The welding current was limited on the low end by insufficient fusion and at the high end by expulsion or surface spitting. The various weld defects associated with improper welding current are shown in Figs. 1 and 2.

In addition to the nondestructive and metallographic tests made on each group of welds, tension-shear and cross-tension tests were made on both as-welded and

Ernest F. Nippes and **Herbert B. Fishman** are connected with the Welding Laboratory of the Department of Metallurgical Engineering, Rensselaer Polytechnic Institute, Troy, N. Y.

Table 1—Chemical Analysis of Inconel-X Sheet

Gage	Heat	C	Mn	Fe	S	Si	Cu	Ni	Al	Cr	Ti	Cb
0.010 0.015	Y 3576 X	0.05	0.54	6.75	0.007	0.41	0.03	73.59	0.78	14.35	2.43	1.04
0.021	Y 3400 X	0.04	0.40	6.17	0.007	0.41	0.01	74.34	0.71	14.39	2.48	1.01
0.031	Y 3402 X	0.04	0.42	6.58	0.007	0.41	0.02	73.46	0.64	14.89	2.54	1.00
0.062	Y 3401 X	0.04	0.41	6.42	0.007	0.33	0.01	73.78	0.69	14.72	2.48	1.05

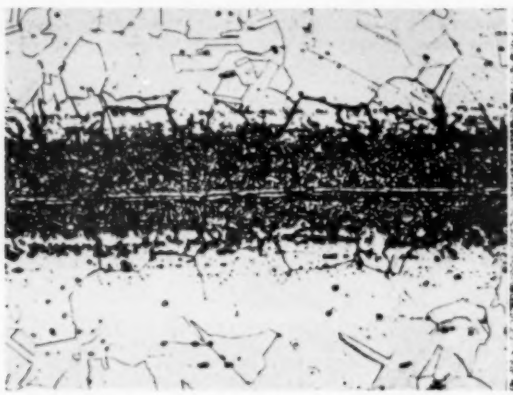


Fig. 1 Weld with insufficient fusion made at low current setting. Note that grains have not coalesced across the interface

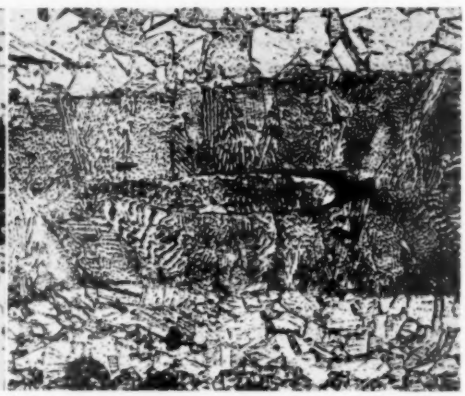


Fig. 2 Weld with porosity caused by expulsion of molten metal. × 50

welded and age-hardened material. Physical testing for pressure-tight seam welds was accomplished by means of the pillow tests.[4,5] Only a relative strength value of the seam weld could be obtained from this test; therefore it was necessary to investigate only the as-welded specimens. The testing procedures and results will be discussed in detail in a later part of the report.

Considerable time was spent in trying to balance the electrode deterioration problem with electrode materials and welding conditions. This electrode difficulty was caused by the excellent high-temperature strength of Inconel X which required high unit welding pressure to insure forging of the fusion zone.

MATERIAL

The Inconel-X sheet used in this Investigation was cold rolled to size and solution treated to leave it in the soft-tempered condition. The chemical analyses of the four different heats supplied by the International Nickel Co. are shown in Table 1. The mechanical properties of each of the gages are shown in Table 2.

The most important properties of Inconel X are its high-tensile, creep, and stress-rupture strengths in the temperature range 1000–1500° F. It can be given several heat treatments for uses at various temperature ranges and strength requirements. For uses from 1100 to 1500° F, best properties are obtained by solution treatment at 2100° F for 4 hr, aging at 1550° F for 24 hr, and finally aging a second time at 1300° F for 20 hr.[6] For uses below 1100° F only the 20-hr aging treatment at 1300° F is required after the solution treatment. In this investigation, 4 hr at 1350° F was considered adequate to show the effect of age hardening upon weld strength as determined by tension-shear and cross-tension tests in spot weld. Pillow-test specimens were tested in the as-welded condition and not in the welded and aged condition. Upon aging, Inconel X becomes much stronger and less ductile, as may be seen in Table 3. This loss of ductility increased the notch sensitivity and, as a result, reduced the cross-tension strengths of the aged specimens, as will be shown later.

Table 2—Mechanical Properties of Inconel-X Sheet*

Gage	Yield strength 0.2% offset, psi	Tensile strength, psi	Elongation in 2 in., %
0.010	54,000	128,700	38.0
0.015	54,400	127,000	45.0
0.021	48,200	108,800	47.0
0.031	45,000	109,100	61.0
0.062	63.100	126,000	52.0

* Cold-rolled strip, soft-temper, solution-treated, as supplied by International Nickel Co.

Table 3—Typical Mechanical Properties of Inconel-X Sheet and Strip (0.025–0.250 In.)[6]

	Solution treated	Solution treated and aged
Tensile strength, psi	100,000–140,000	150,000–175,000
Yield strength, 2% offset, psi	40,000– 80,000	100,000–130,000
% elongation in 2 in.	35–60	20–30
Hardness, Rockwell	77–100B	30–40C

During the processing of Inconel-X sheet, a tenacious oxide film of high resistivity is formed. This film was chemically removed to insure satisfactory and consistent welding by resistance methods. By degreasing all specimens with tetrachloroethylene and then pickling at room temperature for 20 min, in a solution containing:[7]

1000 cc, HnO_3 (concentrated)
1000 cc, H_2O
150 cc, HF (48%)

The surface resistance was lowered and held with consistency for welding to 45 ± 15 microhms. The stability of the optimum current range was highly dependent upon the control exercised during the surface preparation. The major factor involved in the control of surface resistance was not the magnitude of the resistance but its uniformity. It was found advantageous, however, to keep the maximum value below 100 microhms in order to obtain the widest latitude of permissible current. The high inherent resistance of Inconel X, 125 microhm-cm, affects the current range adversely from the start. The heat source for welding is the electrical resistance to current flow in the material and across the interface. The greater the total resistivity becomes, the narrower will be the range of electrical current permissible for welding at optimum conditions.

EQUIPMENT

The spot welder used in this investigation was a press-type Thomson Gibb machine having a maximum electrode force of 5000 lb. The transformer, rated at 200 kva, operated at 60 cycles and 440 v with a turns ratio of 36:1. For the lighter gages, 0.010- and 0.015-in. sheet, a spring-loaded electrode was employed to apply the required low force with uniformity and rapid follow-up during welding.

For the seam-welding portion of this investigation a Federal machine having a maximum electrode force of 4000 lb was utilized. Its transformer was rated at 175 kva with 60 cycles and 440 v and has a turns ratio of 50.2:1. The wheel drive and gearing of this machine were rebuilt to give a full coverage of speeds from 5 to 200 ipm at the maximum electrode force. Previous to rebuilding, skipping and electrode chattering caused serious expulsion at low speeds and high forces. The new drive, lubricated with molybdenum disulfide in a graphite-base grease, completely eliminated this difficulty. Although it was realized that 6000 lb would be the maximum force required in the investigation of the 0.062-in. sheet, it was deemed impossible to attain this force on the existing machine even with the various revisions.

The welding power was drived from a 125-hp, 350-kva motor-generator set operating from a 3-phase, 4160 v, 60-cycle line. The output voltage of the generator was adjustable from 275 to 550 v.

Electronic-type timing and phase controls were used for both spot and seam welding. Since satisfactory welds could be made without the use of slope control, no work was done using this circuitry although the equipment was available. However, it is suggested that slope control may be useful for welding dissimilar thicknesses of Inconel X and for joining Inconel X to other metals.

A complete latitude of "on-off" sequences was available with a minimum of $^1/_2$ cycle "on" time and 1 cycle "off" time. The welding current was controlled by means of phase control and by adjustment of the primary voltage supply to the welding transformer.

Both RWMA Class II and Class III electrodes were employed for seam welding, while only Class II were utilized for spot welding. The physical and mechanical properties of these electrode materials are shown in Table 4.

Table 4—Physical and Mechanical Properties of Electrode Materials

Electrode material	*Elastic limit, psi*	*Ultimate strength, psi*	*Elongation, %*	*Brinell hardness*	*Conductivity, % IACS*
Mallory No. 3, class II	50,000	75,000	15	150	80
Mallory No. 100, Forged Class III	80,000	100,000	10	225	55

A Kelvin double bridge was used to determine the surface resistance of the weld specimens. It was found that an electrode force of 1000 lb was satisfactory for all gages investigated when making these measurements. At forces above 400 lb, the surface resistance versus force curve is relatively flat, as shown in Fig. 3 for 0.010-, 0.031- and 0.062-in. Inconel-X sheet.

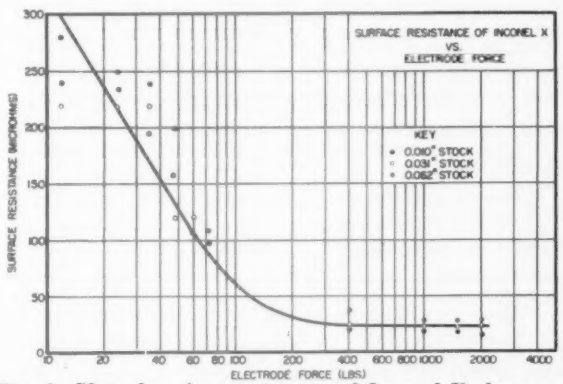


Fig. 3 Plot of surface resistance of Inconel-X sheet vs. electrode force

INSTRUMENTATION

The welding force was calibrated with a deflection-type force gage. The weld times were measured and recorded on a Brush self-inking oscillograph. The seam-welding wheel speeds were checked with an electric timer. For spot welding, the current was measured and computed from I^2t readings made on a General Electric I^2t meter.[8] For short seam-welding sequences of up to 3 cycles on and 6 cycles off, the RMS current, I_{rms}, was calculated by the following formula[4] from the average value of current, I_{avg}, recorded on an Esterline-Angus recording ammeter:

$$I_{rms} = \sqrt{I^2_{avg} \times \frac{(\text{"on" time} + \text{"off" time})}{(\text{"on" time})}}$$

For longer seam-welding sequences, the Esterline-Angus recording ammeter was again employed, but the current readings were calibrated for each on-off relationship used, with the I^2t meter and a pointer-stop ammeter. Good correlation of current values was obtained from the various evaluation methods used.

TESTING

A 150-kv industrial X-ray unit was used for radiographic analysis of spot and seam welds for cracking and porosity. Fine-grained Eastman Kodak Type M X-ray film was used with conditions as shown in Table 5.

Table 5—Conditions for Radiography Using Eastman Kodak Type M Film

Gage, in.	*Voltage, kv*	*Tube current, ma*	*Exposure time, min*	*Tube-film distance, in.*
0.010	50	10	2	36
0.015	60	10	2	36
0.021	70	10	3	36
0.031	90	10	2	36
0.062	110	10	4	36

Mechanical testing of spot welds was accomplished on a Baldwin-Southwark Universal Hydraulic Testing Machine according to RWMA recommendations. The size of specimens used for the various gages is shown in Table 6. Five specimens in both the as-welded, and welded and age-hardened (for 4 hr at 1350 ± 25° F) conditions were tested.

Table 6—Specimen Size for Various Tests

Gage, in.	*Tensile-shear tests of spot welds, in.*	*Cross-tension test of spot welds, in.*	*Pillow tests of seam welds, in.*
0.010	1 x 3	2 x 6	6 x 6
0.015			
0.021			
0.031	1 x 4	2 x 6	6 x 6
0.062	1 1/2 x 5	2 x 6	6 x 6

Pillow tests of seam-welded specimens were made for all sheet thicknesses. A brass pipe of suitable diameter was brazed to the top sheet of the 6- x 6-in. specimen and then a bottom piece also 6- x 6-in. was seam welded to the first to make a 4- x 4-in. enclosed pressure-tight area. Extreme care was required in the brazing procedure to prevent stress-corrosion cracking and subsequent failures in the sheet adjacent to the braze. This cracking during brazing undoubtedly resulted from the stresses which remained after the drilling of the hole in the sheet. By drilling a small hole and bracing a larger diameter nipple, the braze can be made away from the stress area and stress-corrosion cracking can be avoided. An alternate method of brazing involved fluxing and heating of the stressed area to 1800° F, followed by air cooling to 1250° F and then brazing in the normal manner. In both cases, Easy Flo silver-brazing alloy was used for attaching the pipe to the top sheet.

An hydraulic pump system with a Bourdon gage was used to measure the hydrostatic pressure developed prior to failure in the pillow test. The hand-operated pump of the hydraulic test system had a capacity of 4000 psi.

Prior to testing of the pillow-test specimens, the excess metal was trimmed off to within 1/8 in. of the welds[5] and the specimens were then radiographed. During testing, the thin material usually failed in the parent metal at the crease next to the seam weld while the thicker gages failed by shear and plug-type failures.

Metallographic examination was made of spot-weld and seam-weld sections, taken through the centerline of the weld. Additional information was obtained from transverse sections of seam welds. Preparation of these mounts for macroscopic examination required ordinary metallographic technique with modified Marble's Reagent as the etchant. The fused area was measured macroscopically with a Filar eyepiece.

DETERMINATION OF OPTIMUM CONDITIONS

The variables involved in resistance welding are many and quite interdependent. Certain variables were predicted approximately during the initial research. This procedure helped reduce to a minimum the number of welds to be made.

Using an electrode geometry as determined by a method to be explained later and an approximate weld time, a group of weld series were made at various forces with current values ranging from those causing sticking to those causing expulsion. By this method, the force at which porosity was just eliminated at the expulsion

Table 7—Recommended Conditions for the Spot Welding of Inconel X

Sheet thickness, in.	*—Electrode size, in.— Diam*	*Radius*	*Weld time, cycles*	*Weld force, lb*	*Weld current, amp*	*Fusion-zone diam, in.*	*Penetration, %*
0.010	5/32	6	2 (2–4)*	300 (270–330)	7300 (7000–7750)	0.11 (0.11–0.12)	45
0.015	5/32	6	4 (2–6)	400 (350–450)	7400 (7000–7800)	0.11 (0.10–0.12)	45
0.021	3/16	6	6 (6–8)	750 (650–850)	7500 (7100–7900)	0.14 (0.12–0.14)	35
0.031	7/32	6	8 (6–10)	1750 (1600–1900)	9900 (9500–10,200)	0.17 (0.14–0.18)	35
0.062	5/16	10	14 (10–16)	4400 (4200–4700)	16,350 (15,500–17,250)	0.29 (0.27–0.30)	45

* The values within parentheses are the range of variables which are satisfactory for good welds. Since these variables are interdependent, they cannot be independently varied over the range without adjusting other variables to compensate.

Table 8—Results of Mechanical Tests on Inconel-X Spot Welds

Sheet thickness, in.	Tension-shear strength, lb — As-welded	Tension-shear strength, lb — Aged 4 hr at 1350° F.	Normal tension strength, lb — As-welded	Normal tension strength, lb — Aged 4 hr at 1350° F.	Normal tension to shear strength ratio % — As-welded	Normal tension to shear strength ratio % — Aged 4 hr at 1350° F
0.010	320 (310–340)*	460 (450–485)	260 (250–275)	180 (170–200)	81.4	39.2
0.015	510 (480–530)	700 (670–730)	370 (340–400)	270 (240–300)	72.6	38.6
0.021	660 (620–700)	900 (820–980)	510 (410–610)	360 (250–470)	77.2	40.0
0.031	1400 (1300–1500)	1800 (1650–1950)	1000 (880–1120)	680 (540–820)	71.5	37.7
0.062	4300 (4000–4650)	5600 (5200–6000)	3400 (3000–3800)	2400 (2000–2800)	79.1	42.8

* The values within parentheses are the range of strengths accompanying the optimum current range, as illustrated in Figs. 4–8.

limit of current was found. The effect of weld time upon fusion-zone diameter was then studied at this value of force, using current values up to the expulsion limit. Thus, the optimum weld time was found. The force analysis was then repeated if a different time had been used in its determination. With the optimum weld time and force, the current range from 30% penetration to expulsion, excess separation or indentation was found. These values of optimum conditions are reported in Table 7.

At several points within this current range, cross-tension and tension-shear specimens were welded and tested, half of the specimens being age hardened previous to testing. The curves obtained by this work, as shown in Figs. 4 through 8, will be discussed later. Table 8 lists the values of weld strength at optimum conditions taken from these curves.

The determination of seam welding conditions was simplified by the aid of the spot welding values for the basic variables. Although these were different in magnitude from the seam welding optimums to be found, a proportional relationship could be established. This

Fig. 4

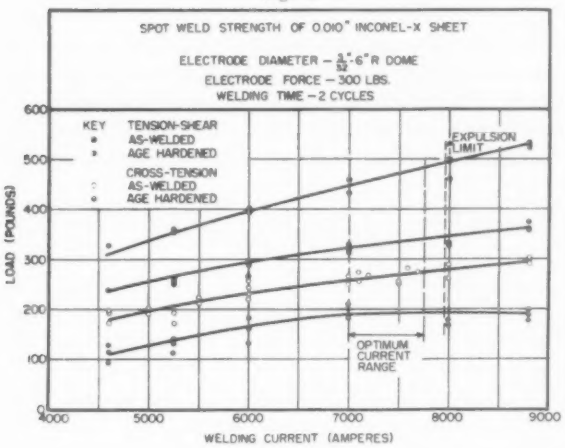
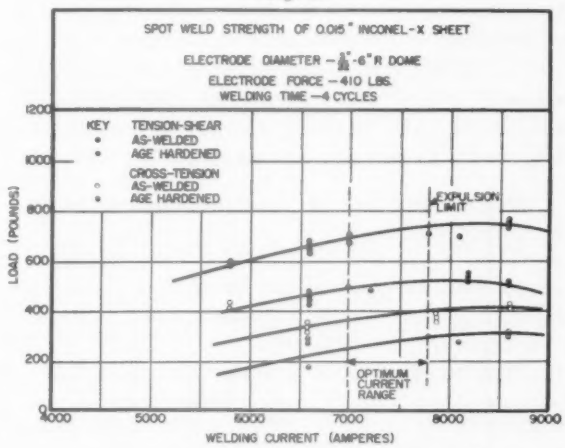


Fig. 5



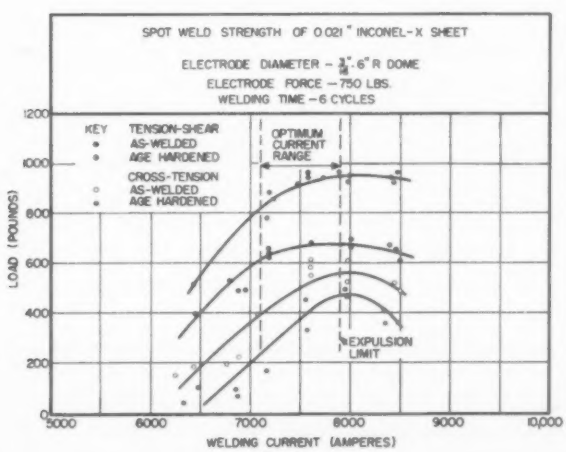


Fig. 6

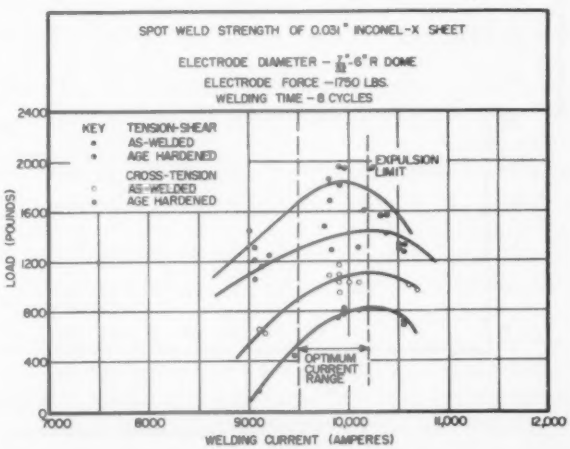


Fig. 7

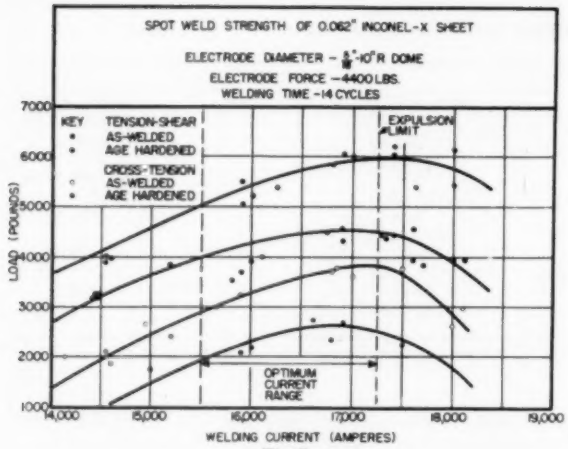


Fig. 8

Figs. 4–8 Plot of spot weld strength of 0.010-, 0.015-, 0.021-, 0.031- and 0.062-in. Inconel-X sheet vs. welding current

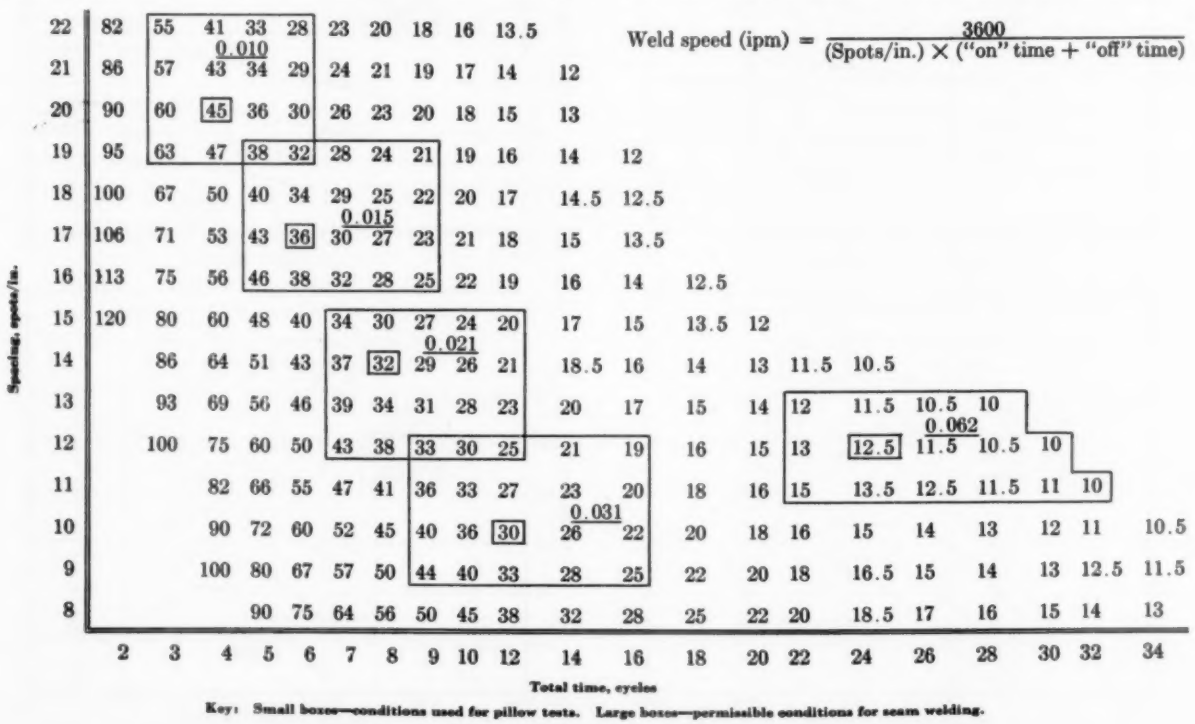
was accomplished by modifying the values of force, current and time for the larger contact area, the short-circuit effect of previously fused zones and the preheat of previous welds.

Wheel geometry was the first consideration in the seam welding procedure. The selection of this variable will be discussed later. Using approximate values for the other variables, 12-in. long seam welds were made at various forces. Starting with low currents at the beginning of the 12-in. seam, the magnitude of current was increased uniformly along the weld. These welds, radiographed to show the start of porosity, were torn apart to show the start of plug failure. Since the tear test rarely pulled plugs with less than 25% fusion, this analysis gave the approximate current latitude from 30% fusion to porosity or expulsion. The optimum force was chosen as the lowest that would eliminate porosity at the expulsion limit. Then, with the optimum force, this procedure was repeated for various weld spacings and combinations of "on" times and "off" times. This survey gave the approximate limits of permissible welding conditions shown in Fig. 9. It must be kept in mind that wheel speed, weld spacing and total "on" and "off" time are all interdependent:

$$\text{Wheel speed, ipm} = \frac{3600}{(\text{Spots-in.}) \times (\text{"on"-time} + \text{"off"-time})}$$

The sets of conditions which seemed to be best or had wide current ranges were then reinvestigated. In this case, however, each specimen was made at a constant current value. Each series of welds for each set of conditions had a complete coverage of specimens with

$$\text{Weld speed (ipm)} = \frac{3600}{(\text{Spots/in.}) \times (\text{"on" time} + \text{"off" time})}$$



Key: Small boxes—conditions used for pillow tests. Large boxes—permissible conditions for seam welding.

Fig. 9 Relationship of weld time, spacing and speed

Table 9—Recommended Seam Welding Conditions for Inconel X

Gage in.	Wheel geometry	Speed, ipm	Force, lb	Current, amp	Timing Cycles "On"	Timing Cycles "Off"	Spacing spots/in.	Penetration, %	Fusion zone width, in.
0.010	Mallory No. 3, 1/8–3 in. radius, 9-in. wheel diam	45 (28–63)†	400 (350–450)	3600 (3200–4000)	1 (1/2–1 1/2)	3 (2–5)	20 (19–22)	(30–45)	0.11
0.015	Mallory No. 3, 1/8–3 in. radius, 9-in. wheel diam	36 (21–56)	700 (625–775)	3900 (3600–4200)	2 (1–2)	4 (3–6)	17 (16–19)	(30–45)	0.12
0.021	Mallory No. 3, 5/32–3 in. radius 9-in. wheel diam	30 (20–43)	1400 (1250–1550)	8000 (7700–8400)	3 (2–4)	6 (5–8)	14 (12–16)	(30–45)	0.14
0.031	Mallory No. 100, 3/16–3 in. radius, 9-in. wheel diam	30 (19–40)	2300 (2100–2500)	8500 (8100–8900)	4 (3–5)	8 (5–10)	10 (9–12)	(30–50)	0.17
0.062*	Mallory No. 100, 3/16–6 in. radius, 8-in. wheel diam*	12.5 (8–15)*	4000* min	10,300 (10,000–10,600)*	8 (7–9)*	16 (15–28)*	12 (11–13)*	(30–65)	0.18

* Not optimum conditions, but satisfactory when sufficient force is not available.

† The values within parentheses are the range of variables which are satisfactory for good welds. Since these variables are interdependent, they cannot be varied independently over the range without adjusting other variables to compensate.

current values from the start of plug failure to those at expulsion. Each of these specimens were radiographed and sectioned.

From the metallographic analysis, it was possible to make a critical survey of the fusion zone of spot and seam welds. The diameter or width of the fusion zone, the penetration of the fusion zone and the fusion-zone overlap were measured. Of course, porosity, cracking, misshaped welds and other fusion-zone defects could also be detected. The larger boxes shown on Fig. 9 outline the sets of welding conditions that met all the requirements of the criteria for optimum welding conditions listed in the Introduction. The pillow-test run was then made at the optimum conditions which are shown in Table 9. The relationship of these optimum conditions for each gage is also shown by the small boxes in Fig. 9.

ELECTRODE GEOMETRY

Consistency of weld strength for both spot and seam welds depends upon assurance of a plug-type failure upon fracture. This means that the diameter of the fused zone must be large enough to effect a failure through the base metal around the perimeter of the weld and not by shear along the weld interface. The approximate value of minimum diameter of the fusion zone was determined by the formula, 0.1 in. + $2t$, where t is the single-sheet thickness in inches. The actual electrode diameter was selected at least 10% larger than the minimum calculated by the formula, to the nearest integral 1/32 of an inch. As an example, in the spot welding of 0.010- and 0.015-in. sheet, 5/32-in. diam electrodes were used. This minimum size is a compromise between weld consistency, minimum electrode wear and prevention of mushrooming.

The use of the restricted-dome electrode was believed to be best for the spot welding of Inconel X, since maintenance economy was improved by this shape at the high electrode forces required. The radius of curvature of the dome of the electrode was selected for minimum deterioration rate and minimum difficulty of alignment.

Electrode alignment was considered an important factor. Without excellent alignment, the higher ranges of current could not be reached without expulsion or surface spitting. Electrodes for both spot and seam welding must be uniform in size, symmetrical in face at operating force and concentric or true-running at that force.

At the higher forces required for seam welding 0.031 and 0.062-in. Inconel-X sheet, Mallory 100, Class III electrode material was employed to improve electrode life. Unfortunately, the higher electrical resistivity of Mallory 100 material reduced the welding current range and increased the tendency toward surface spitting. Therefore, Mallory No. 3, Class II electrode materials were used for all other cases.

WELDING CURRENT

Welding current in both spot and seam welding is a most important variable. The major influences on the current range are produced by weld force, metal resistivity, ratio of internal resistance to contact resistance, the preheat and short-circuit effect of previous welds in seams, and the time of duration of the current pulse.

As the current is increased in magnitude, the fusion zone becomes larger until the expulsion limit is reached. At this value of the current, the weld force and thermal expansion cause molten metal to be displaced from the fusion zone along the interface, as was shown in Fig. 2. In this case, because of the shrinkage upon transformation from the liquid to the solid state, a void is left in the fusion zone. If the thermal gradient is low, from the edge of the fusion zone to the sheet surface, metal may be expelled along cored grain boundaries, forming "intergranular rivers." This is one of the causes of surface spitting, an example of which is shown in Fig. 10. Note that the "intergranular rivers" extend all the way to the sheet surface. In this case also, voids, called weld porosity, are usually left upon cooling. These voids, of course, will be points of high stress concentration and will diminish the strength of the welds causing erratic results in the strength curves above the expulsion and surface-spitting limits.

As the weld force was increased, it was found that

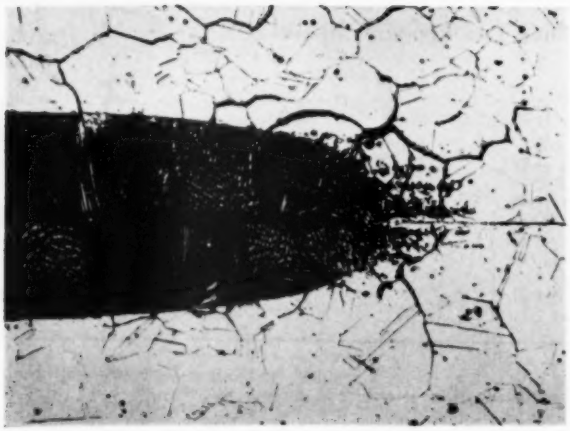


Fig. 10 Transverse section of a seam weld in which surface spitting and extended coring were coincident. × 75

surface resistance decreased and higher currents were required to obtain equal fusion-zone sizes. In seam welding thin material, it was found that surface spitting occurred with low forces before expulsion, while with higher forces expulsion occurred first. The tendency for surface spitting in thin materials results from a low-temperature gradient. The low-temperature gradient is in turn produced by a high-surface contact resistance as compared to the internal resistance. The widest range of the optimum current values was found when expulsion and surface spitting occurred simultaneously. In thick material the rate of heat abstraction into the base metal was fast enough to eliminate trouble from surface spitting.

The welding current required for seam welding is reduced by the heat from previously fused zones. However, the short-circuit current passing through these previously fused zones tends to raise the current required. The relative effects of these factors is determined by the weld spacing (spots/in.) and will be discussed later.

WELD FORCE

The main criteria limiting the values of the weld force range were the elimination of porosity at the low end of the force range, and the prevention of excess sheet separation and indentation at the high end. The minimum values, as reported in Table 7, were determined as the lowest force that would give porosity-free welds at a value of welding current just below the expulsion limit. Slightly lower forces can be used at lower current values. The maximum force, as reported in Table 7, was that which gave either (1) a maximum of 10% sheet separation or 5% indentation at the high values of current and time, or (2) too narrow an optimum current range.

In general it was noted that as the sheet thickness increased, the optimum weld force increased linearly. A comparison of the optimum weld forces for Inconel X

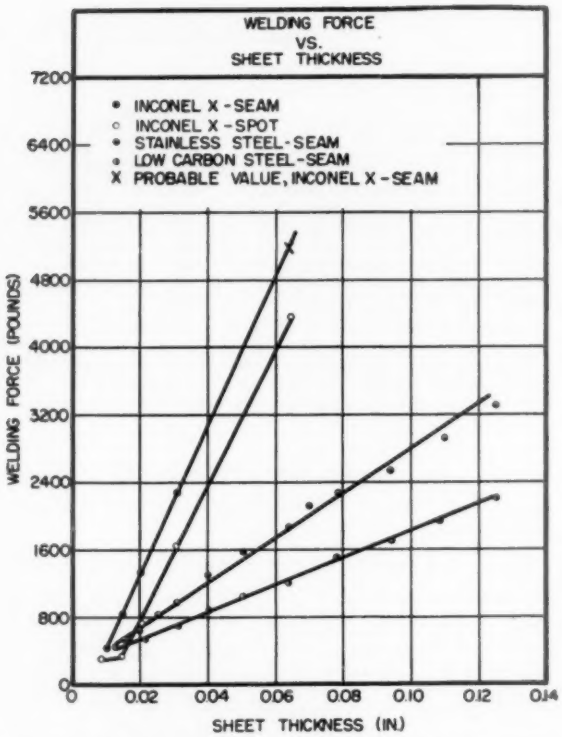


Fig. 11 Plot showing weld force vs. sheet thickness for various materials

with those previously determined for other materials is made in Fig. 11.[5,7]

WELD SPACING

Since greater economy is usually gained with higher permissible welding speeds and less energy consumption, it is advantageous to make as few welds per inch as possible and still maintain a pressure-tight seam with minimum overlap of 10–25%. However, in the seam welding of Inconel X, high unit pressures must be maintained to eliminate porosity. As the welding force increases, the current required to give minimum penetration and proper nugget width increases. The larger the fusion-zone size, the greater was the tendency for expulsion and porosity. At high welding currents and forces, the values of indentation and sheet separation also increased. For these reasons, it was necessary to increase the number of spots per inch to reduce the fusion-zone size until the widest possible range for each variable was obtained. A good weld with proper overlap is shown in Fig. 12, while Fig. 13 shows a weld with insufficient overlap at low current.

With increased fusion-zone overlap, the short-circuit current is increased, the temperature gradient is decreased, and therefore, the tendency for surface spitting or surface burning is increased. When welding at the high end of the current range on 0.010, 0.015 and 0.021-in. sheet, the best balance of weld spacing was indicated by the simultaneous occurrence of expulsion and surface spitting.

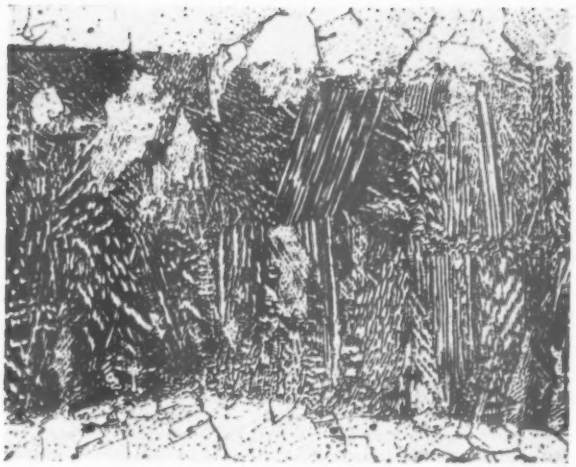


Fig. 12 Satisfactory seam weld, illustrating sufficient overlap and evidence of coring. × 50

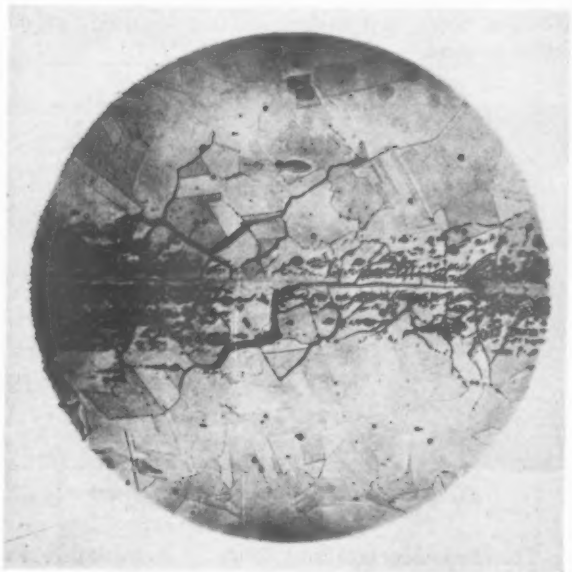


Fig. 13 A seam weld with insufficient overlap and fusion. × 50

WELDING TIME

Weld time must be long enough to allow the fusion zone to develop fully. However, the longer the metal is kept molten, the greater will be electrode indentation, sheet separation and the tendency for surface spitting. Apparently, the short-circuit and preheat effect of previous fusion zones in seam welding reduced the required "on" time to approximately half that of spot welding.

Weld time was determined in the spot welding of Inconel X by making a series of weld strength versus current curves, with time as the parameter. For a given sheet thickness, these strength-current curves were found to approach the same maximum value of weld strength. As weld times were increased, weld strength consistency improved, and electrode indentation and sheet separation increased. The weld time chosen was just long enough to give a full fusion zone without excess indentation. In some cases the reported weld time may be increased if it is desired to improve weld strength consistency. Unfortunately, the advantage gained by increasing the weld time is offset by increased sheet separation and indentation.

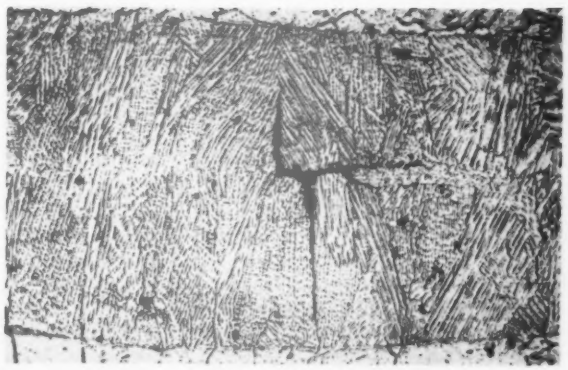


Fig. 14 Cracking in the fusion zone of a seam weld made at low force. × 50

DISCUSSION

There should be no difficult problems in the spot and seam welding of Inconel X in the soft-tempered condition provided: (*a*) that reasonable care is exercised in the control of the welding conditions used, (*b*) that the stock is given a uniform surface treatment and (*c*) that the welding machines used are designed for surface at the optimum welding conditions.

During this research, very little trouble with cracking within the fused zone or the adjacent material was encountered. However, with low electrode forces, cracking does occur in seam welds as is shown in Fig. 14. The major defect found in the zones of fusion was porosity caused by:

1. Insufficient weld force.
2. Expulsion of metal.
3. Surface spitting.

Sometimes when expulsion or surface spitting occurred there was no porosity. However, usually under these conditions, there was severe sheet indentation. This indentation was not necessarily caused by high weld force but by the conditions of expulsion. In most cases, the problem of weld porosity could be eliminated by going to higher weld forces and by avoiding expulsion and surface spitting. The circumstances of the seam welding of 0.062-in. sheet were an exception and will be discussed later. Occasionally welds would appear to be cracked at the interface as in Fig. 15 but at higher magnification, Fig. 16, it may be seen that the formation is dendritic.

Characteristic of most spot and seam welds in Inconel-X sheet was the phenomenon of intergranular melting, known as coring. At low magnification the structure appears to be a crack which starts at the edge of

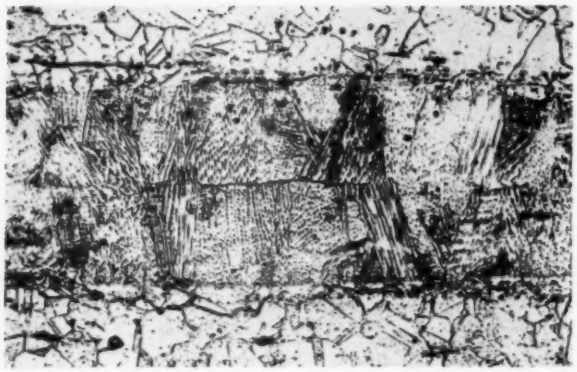


Fig. 15 Dendritic interface of a sound weld that appears to be cracked. × 50

the fusion zone and works its way out along the grain boundaries. Figure 17 shows a typical example of coring at low magnification. It may be seen in Fig. 18 that this area is not a crack but is completely dendritic. This research gave no indications that coring is detrimental to the mechanical properties of the welds.

However, in many cases where surface spitting occurred due to welding above the upper limit of current, other conditions being optimum, coring could be traced from the fusion zone to the surface of the sheet at which spitting occurred. Such evidence was found only in 0.010, 0.015 and 0.021-in. sheet. Figure 10 shows a typical example of an "intergranular river," i.e., grain boundary coring, in a seam weld.

The fact that surface spitting was aggravated by the higher resistivity of Mallory No. 100 electrodes points to the relationship between the extent of coring and the thermal gradient from weld nugget to sheet surface. As the gradient was decreased, the tendency for surface spitting increased along with the extent of the coring. By increasing the weld spacing, the effect of the short-circuit current and preheat were reduced, as was the tendency for spitting. This reasoning is substantiated by the complete absence of surface spitting

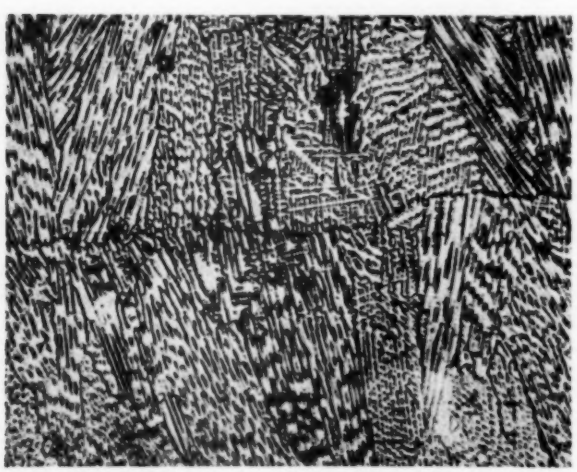


Fig. 16 Dendritic interface of weld illustrated in Fig. 15, at higher magnification, showing dendritic structure of a sound weld. × 150

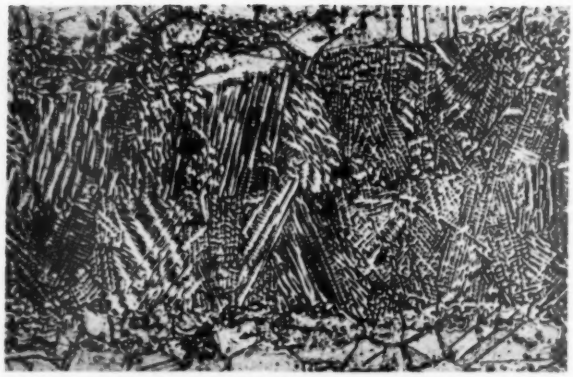


Fig. 17 Coring in a sound seam weld. × 50

during spot welding. The fact that sheet thickness affects the temperature gradient was shown by the fact that expulsion occurred before surface spitting in 0.031- and 0.062-in. sheet, while both expulsion and surface spitting occurred simultaneously in 0.021- and 0.015-in. sheet, and surface spitting occurred first in 0.010-in. sheet.

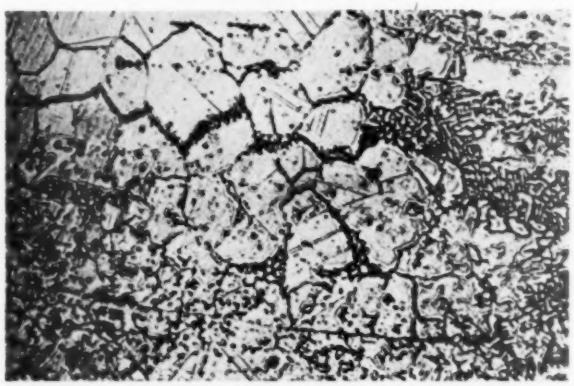


Fig. 18 Coring in a sound weld. × 250

The phenomenon called "tailing" is recognizable as a certain type of misshaped fusion zone, as shown in Fig. 19. It was noted most frequently when welding at high speeds and forces with thin material (0.021 in. or less). It is believed that "tailing" results from the

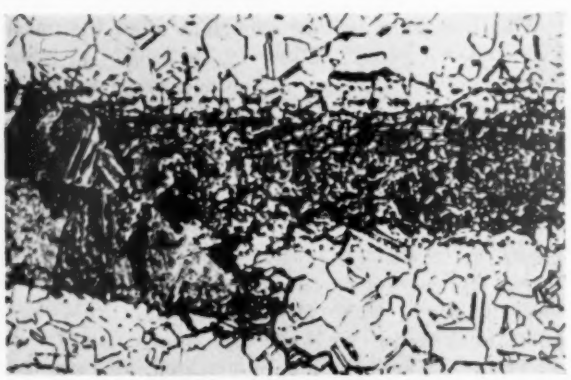


Fig. 19 "Tailing" in a seam weld. × 100

Fig. 20

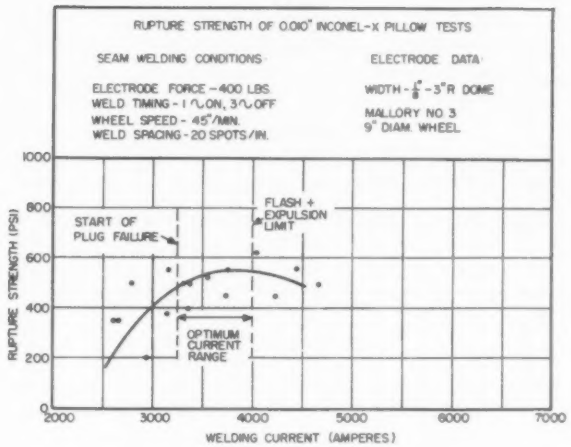
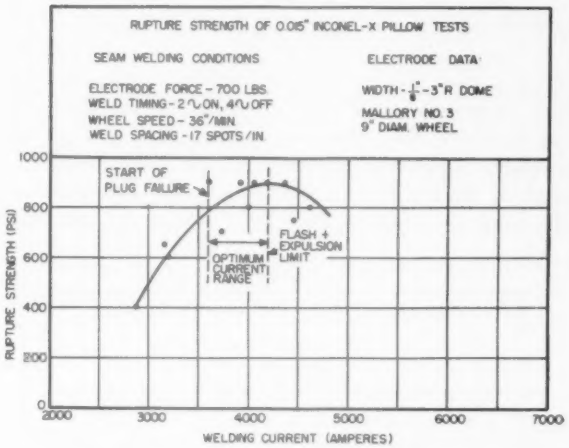

RUPTURE STRENGTH OF 0.010" INCONEL-X PILLOW TESTS
SEAM WELDING CONDITIONS
ELECTRODE FORCE – 400 LBS.
WELD TIMING - 1 CYCLE ON, 3 CYCLE OFF
WHEEL SPEED - 45"/MIN.
WELD SPACING - 20 SPOTS/IN.
ELECTRODE DATA
WIDTH - 1/8" - 3" R DOME
MALLORY NO. 3
9" DIAM. WHEEL
START OF PLUG FAILURE
FLASH + EXPULSION LIMIT
OPTIMUM CURRENT RANGE
RUPTURE STRENGTH (PSI)
WELDING CURRENT (AMPERES)

Fig. 21


RUPTURE STRENGTH OF 0.015" INCONEL-X PILLOW TESTS
SEAM WELDING CONDITIONS
ELECTRODE FORCE – 700 LBS.
WELD TIMING - 2 CYCLE ON, 4 CYCLE OFF
WHEEL SPEED - 36"/MIN.
WELD SPACING - 17 SPOTS/IN.
ELECTRODE DATA
WIDTH - 1/8" - 3" R DOME
MALLORY NO. 3
9" DIAM. WHEEL
START OF PLUG FAILURE
FLASH + EXPULSION LIMIT
OPTIMUM CURRENT RANGE
RUPTURE STRENGTH (PSI)
WELDING CURRENT (AMPERES)

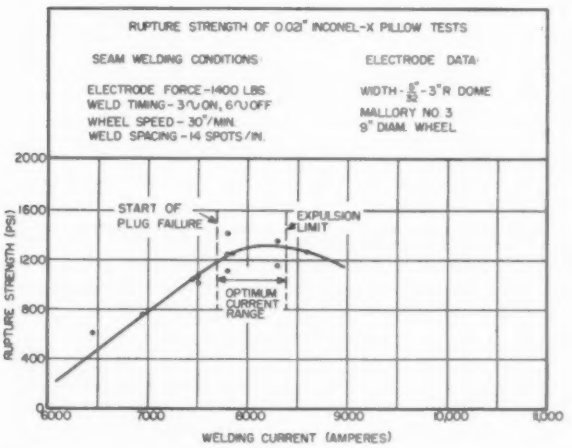

RUPTURE STRENGTH OF 0.021" INCONEL-X PILLOW TESTS
SEAM WELDING CONDITIONS
ELECTRODE FORCE – 1400 LBS.
WELD TIMING - 3 CYCLE ON, 6 CYCLE OFF
WHEEL SPEED - 30"/MIN.
WELD SPACING - 14 SPOTS/IN.
ELECTRODE DATA
WIDTH - 1/8" - 3" R DOME
MALLORY NO. 3
9" DIAM. WHEEL
START OF PLUG FAILURE
EXPULSION LIMIT
OPTIMUM CURRENT RANGE
RUPTURE STRENGTH (PSI)
WELDING CURRENT (AMPERES)

Fig. 22

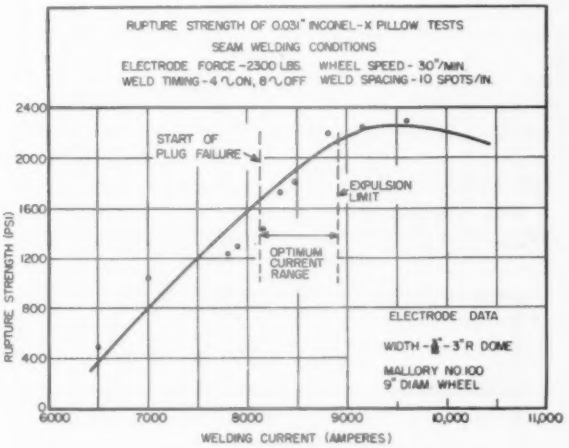

RUPTURE STRENGTH OF 0.031" INCONEL-X PILLOW TESTS
SEAM WELDING CONDITIONS
ELECTRODE FORCE – 2300 LBS.
WELD TIMING - 4 CYCLE ON, 8 CYCLE OFF
WHEEL SPEED - 30"/MIN.
WELD SPACING - 10 SPOTS/IN.
START OF PLUG FAILURE
EXPULSION LIMIT
OPTIMUM CURRENT RANGE
ELECTRODE DATA
WIDTH - 1/8" - 3" R DOME
MALLORY NO 100
9" DIAM. WHEEL
RUPTURE STRENGTH (PSI)
WELDING CURRENT (AMPERES)

Fig. 23

Figs. 20–23 Plot of rupture strength vs. welding current for 0.010-, 0.015-, 0.021- and 0.031-in. Inconel-X pillow tests

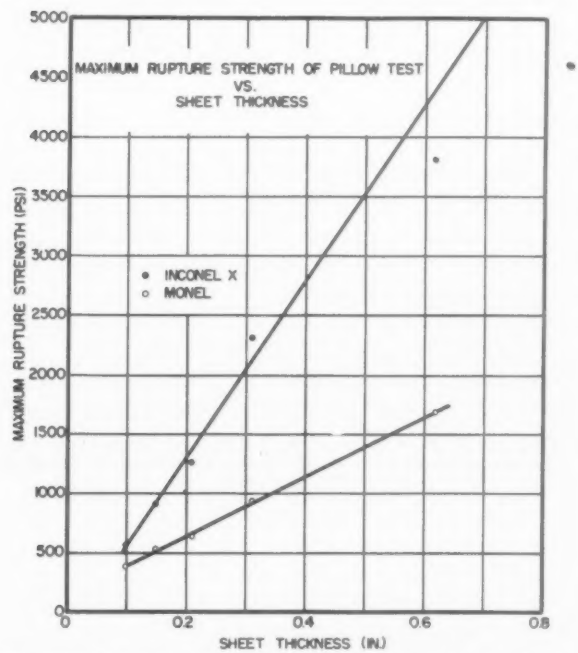


Fig. 24 Plot of maximum rupture strength vs. sheet thickness for Inconel X and Monel metal

phenomenological advent of a certain combination of weld spacing and "off" time at high welding speeds and high forces. "Tailing" occurs when the welding current pulse is initiated at the instant when the electrode wheel is riding the shoulder between the last spot and the spot to be formed. During the formation of the pre-

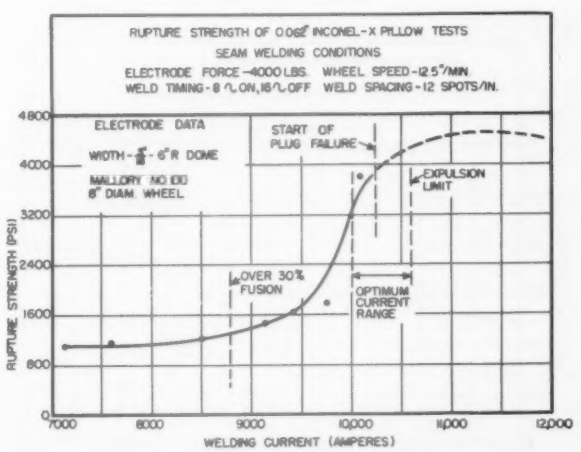

RUPTURE STRENGTH OF 0.062" INCONEL-X PILLOW TESTS
SEAM WELDING CONDITIONS
ELECTRODE FORCE – 4000 LBS.
WELD TIMING - 8 CYCLE ON, 16 CYCLE OFF
WHEEL SPEED - 12.5"/MIN.
WELD SPACING - 12 SPOTS/IN.
ELECTRODE DATA
WIDTH - 1/8" - 6" R DOME
MALLORY NO 100
8" DIAM. WHEEL
START OF PLUG FAILURE
EXPULSION LIMIT
OVER 30% FUSION
OPTIMUM CURRENT RANGE
RUPTURE STRENGTH (PSI)
WELDING CURRENT (AMPERES)

Fig. 25 Plot of rupture strength vs. welding current for 0.062-in. Inconel-X pillow test

vious spot, the electrodes indent a few thousandths of an inch while the metal is plastic. This forging action forms a shoulder over which the wheels must ride in order to move to the next weld position. If the current pulse is initiated at the instant when the wheels are on the shoulder, then the restricted contact area of the shoulder causes a high current density and forms the head of the fused zone. Of course, the remainder of the nugget is smaller in size than the head and since the fusion zone tapers off, it has been called the tail. Surface spitting often occurs with "tailing" and for this reason it is best to avoid conditions which produce this phenomenon.

DISCUSSION

Seam Welding Results

The results of a series of tests for rupture strength of

Fig. 26

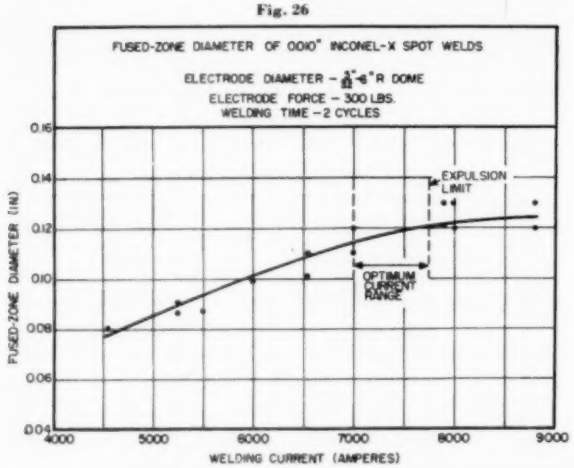
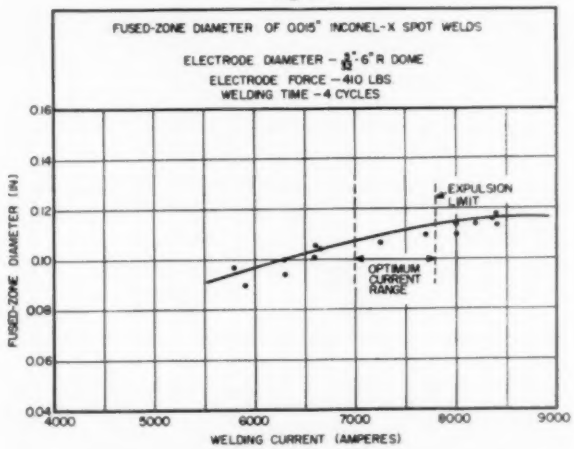

FUSED-ZONE DIAMETER OF 0.010" INCONEL-X SPOT WELDS
ELECTRODE DIAMETER – 3/16"-6"R DOME
ELECTRODE FORCE – 300 LBS.
WELDING TIME – 2 CYCLES
EXPULSION LIMIT
OPTIMUM CURRENT RANGE
FUSED-ZONE DIAMETER (IN.)
WELDING CURRENT (AMPERES)

Fig. 27


FUSED-ZONE DIAMETER OF 0.015" INCONEL-X SPOT WELDS
ELECTRODE DIAMETER – 3/16"-6"R DOME
ELECTRODE FORCE – 410 LBS.
WELDING TIME – 4 CYCLES
EXPULSION LIMIT
OPTIMUM CURRENT RANGE
FUSED-ZONE DIAMETER (IN.)
WELDING CURRENT (AMPERES)

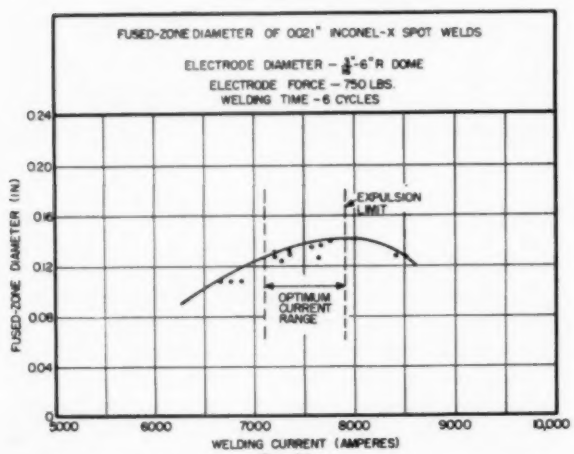

FUSED-ZONE DIAMETER OF 0.021" INCONEL-X SPOT WELDS
ELECTRODE DIAMETER – 3/16"-6"R DOME
ELECTRODE FORCE – 750 LBS.
WELDING TIME – 6 CYCLES
EXPULSION LIMIT
OPTIMUM CURRENT RANGE
FUSED-ZONE DIAMETER (IN.)
WELDING CURRENT (AMPERES)

Fig. 28

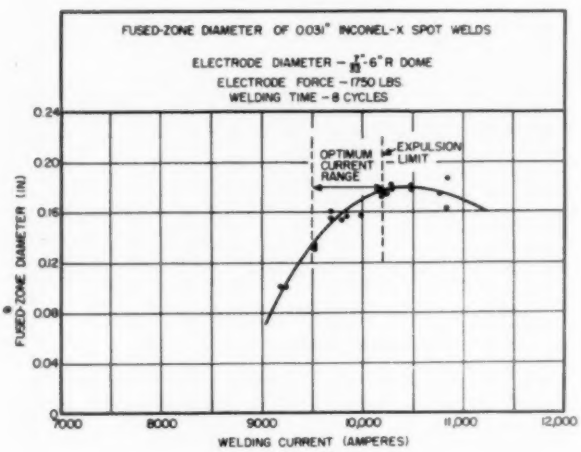

FUSED-ZONE DIAMETER OF 0.031" INCONEL-X SPOT WELDS
ELECTRODE DIAMETER – 7/16"-6"R DOME
ELECTRODE FORCE – 1750 LBS.
WELDING TIME – 8 CYCLES
OPTIMUM CURRENT RANGE
EXPULSION LIMIT
FUSED-ZONE DIAMETER (IN.)
WELDING CURRENT (AMPERES)

Fig. 29

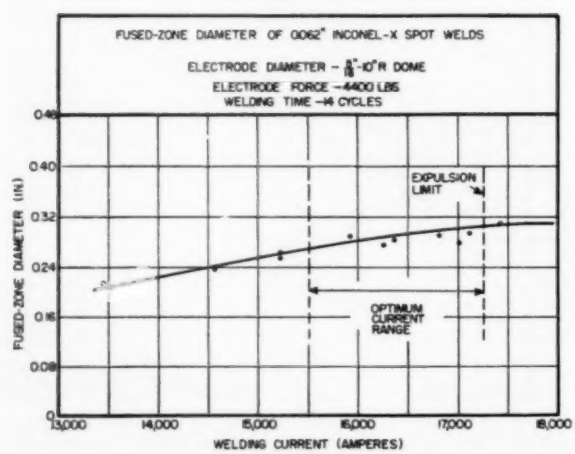

FUSED-ZONE DIAMETER OF 0.062" INCONEL-X SPOT WELDS
ELECTRODE DIAMETER – 3/8"-10"R DOME
ELECTRODE FORCE – 4400 LBS
WELDING TIME – 16 CYCLES
EXPULSION LIMIT
OPTIMUM CURRENT RANGE
FUSED-ZONE DIAMETER (IN.)
WELDING CURRENT (AMPERES)

Fig. 30

Figs. 26–30 Plot of fused-zone diameter vs. welding current for 0.010-, 0.015-, 0.021-, 0.031- and 0.062-in. Inconel-X spot welds

seam-welded pillow-test specimens, Figs. 20 through 23, show that at optimum welding conditions the maximum rupture strength is proportional to the sheet thickness. This was also found to be true in this laboratory for Monel metal seam welds.[4] Figure 24 shows the maximum rupture strength curves for Inconel X and Monel as a function of sheet thickness. All of the specimens broken at these maximum or optimum values gave plug-type failures. The only exception was that of 0.062-in. Inconel X which failed in shear. The rupture strengths of shear failures depends upon fusion-zone width, while the strength of plug failures depends upon sheet thickness. The welds made with undersized-width wheels have smaller width fusion zones and, therefore, will yield lower weld strength in the range of currents failing in shear. Figure 25 shows the rupture strength curve for seams in 0.062-in. Inconel X. If this curve is compared with those of the other gages the dip caused by insufficient weld width will be obvious. Although there was sufficient fusion, the nature of the specimen caused a shear-type failure even at currents close to the expulsion limit. Although a considerable effort was made, it was impossible to determine the optimum seam welding conditions for 0.062-in. Inconel X sheet. From the spot welding conditions and preliminary seam welds made on the various gages, it was estimated that the optimum seam welding force would be approximately 5500 lb with the proper electrode geometry. Unfortunately, the capacity of the available seam welder was only 4000 lb. Therefore, in this investigation, porosity in seam welds in 0.062-in. Inconel X was eliminated by reducing the electrode contact area and thus attaining the required unit pressure. The welding conditions for 0.062-in. material reported in Table 9 are for these undersized-width welds. They are free from defects but can only be made with slow welding speeds. Under certain conditions where plug failures occur, these seam welds will develop full rupture strength.

Spot Welding Results

As the spot welding current was increased the fusion-zone penetration and diameter increased. The increase of fusion-zone diameter with current is shown in Figs. 26 through 30. If these curves are compared to the weld strength load versus welding current curves in Figs. 4 through 8, it may be seen that excellent correlation was obtained. The optimum current range as determined by the 30% fusion to expulsion criterion is marked on both sets of curves. Plug-type failures were usually obtained at or below the lower limit of current. As the fusion-zone diameter increased, the strength of the welds increased until the expulsion limit was reached. At currents above the expulsion limit, both fusion-zone size and weld strength drop or become erratic.

The relative values of spot weld strength for the cross-tension and tension-shear tests may at first seem strange. From Table 8 and Figs. 4 through 8, it may be seen that age hardening the tension-shear specimens increased their strength, while the same treatment of the cross-tension specimens decreased their strength. In the as-welded condition the cross-tension to tension-shear ratios were approximately 75 ± 5%. However, in the age-hardened condition this ratio was only 40 ± 3%. The reason for the loss of strength on aging of cross-tension specimens was the increased effect of the stress concentration factor upon failure of the more brittle material. This loss in ductility upon aging, shown previously in Table 3, is typical of the behavior of precipitation-hardening alloys.

SUMMARY AND CONCLUSIONS

The following observations were made during the determination of the optimum spot and seam welding conditions for 0.010-, 0.015-, 0.021-, 0.031- and 0.062 Inconel-X sheet.

1. There should be no difficult problems in the spot and seam welding of Inconel X in the soft-tempered condition providing:
   - (*a*) That reasonable care is exercised in the control of the optimum welding conditions used.
   - (*b*) That the stock is given a uniform surface treatment.
   - (*c*) That the welding is accomplished on machines designed to operate at those optimum welding conditions.

2. The criteria for good spot and seam welds in Inconel X are as follows:
   - (*a*) No porosity or cracking in the fusion zone.
   - (*b*) Fusion-zone penetration be from 30 to 80% of the total sheet thickness.
   - (*c*) Sufficiently wide current range from 30% fusion to the expulsion or flash (surface spitting) limit.
   - (*d*) From 10 to 25% overlap of fusion zone for pressure-tight seam welds.
   - (e) Less than 5% sheet indentation or 10% sheet separation.

3. The optimum weld force for spot and seam welding is a linear function of sheet thickness.

4. Weld strength consistency for spot welds may be improved by increasing the weld time, but care must be taken not to exceed the sheet separation or indentation limits.

5. The fused diameter or width should be large enough to cause plug failure when 30% penetration is attained.

6. Increasing the fusion-zone overlap reduces the tendency for expulsion, and thereby broadens the optimum current range during seam welding.

7. The maximum rupture strength of pillow-test specimens is a linear function of sheet thickness.

8. This research gave no indication that coring was detrimental to the mechanical properties of the welds.

ACKNOWLEDGMENTS

The authors wish to acknowledge the sponsorship of this experimental investigation by The International Nickel Co., Inc., and to thank Robert M. Wilson of that company for his advice and cooperation.

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An Evaluation of Plastic Analysis as Applied to Structural Design

Discussion by Nicholas J. Hoff

I read with great interest the summary of the work on limit design carried out at Lehigh University as presented by Bruce G. Johnston, C. H. Yang and Lynn S. Beedle, in the article entitled "An Evaluation of Plastic Analysis as Applied to Structural Design." Complementing the historical part of the paper, I would like to add a few remarks which might contribute to a clarification of the origin of limit design.

Through a lucky coincidence, information reached the writer that Dr. Gábor Kazinczy, who had been credited with an early publication on limit design, was now working in Sweden. When requested, Dr. Kazinczy sent a number of his original publications to the writer. The data presented below are based on these publications and on some remarks contained in Dr. Kazinczy's letter.

In 1913 Dr. Kazinczy, a 25-year-old engineer in the employ of the city of Budapest, Hungary, was assigned the duty of carrying out experiments with girders of a new roof structure and of evaluating the test results. He found the load-carrying capacity of the steel beams considerably greater than was expected from an analysis and he came to the conclusion that calculations based on the theory of elasticity had to be discarded when the collapse load of a structure was sought. He proposed calculations on the basis of plastic deformations and became the originator of limit design. The description of his tests as well as his proposed method of analysis was published in the Hungarian periodical *Betonszemle;* the title of his article was "Kisérletek befalazott tartókkal" ("Experiments with Clamped Girders"); and the article appeared in the following three issues of the periodical: Vol. 2, No. 4, p. 68, Apr. 1, 1914; Vol. 2 No. 5, p. 83, May 1, 1914; and Vol. 2, No. 6, p. 101, June 1, 1914. The most significant part of the article is printed on p. 102; a translation of this part from the Hungarian is given at the end of this report.

According to a communication from Dr. Kazinczy, his method of proportioning beams was used in Budapest in the twenties, and analyses based on it were accepted by the building department of the city as proof of the required safety of buildings. He mentioned the method for the first time at an international congress in Vienna in 1928 when Professor Maier-Leibnitz of Stuttgart presented the results of his experiments with beams on several supports and showed that they disagreed with elastic theory. At the same congress, Kazinczy advocated the adoption of a concept of safety based on the probability of collapse. A reference to this can be found on p. 656 of the Final Report of the Third Congress of the International Association for Bridge and Structural Engineering, Liège, Belgium, 1948. (See also the published discussion of the paper "Sicherheitsgrad und Beanspruchung," by W. Gehler, in the Proceedings of the congress in Vienna.)

In 1930, at the International Congress for Metallic Structures held in Liège, Belgium, Kazinczy presented a paper on limit design under the title "Bemessung von statisch unbestimmten Konstruktionen unter Berücksichtigung der bleibenden Formänderungen" ("Proportioning of Statically Indeterminate Structures with Consideration of the Permanent Deformations"). At the congress, he met Professor N. C. Kist, of Delft, Holland, for the first time, who had chosen limit design as his inaugural address at the Polytechnic Institute of Delft in 1917.

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Paper by Bruce G. Johnston, C. H. Yang and Lynn S. Beedle was published in the Supplement to the May 1953 issue of THE WELDING JOURNAL, pp. 224-s–239-s.

In 1932 Kazinczy published a comprehensive article on limit design in the Hungarian periodical *A Magyar Mérnök és Epitész-Egylet Közlönye* (*Journal of the Hungarian Society of Engineers and Architects*) under the title "Statikai értelemben határozatlan szerkezetek méretezése a maradandó alakváltozások figyelem bevételével" ("Proportioning of Statically Indeterminate Structures with Consideration of the Permanent Deformations," 66, No. 9-10, 41, Feb. 28, 1932, and 66 No. 11-12, 57, Mar. 13, 1932). This was followed by a 107-page book entitled *Az anyagok képlékenységének jelentösége a tartószerkezetek teherbirása szempontjából* ("*The Significance of the Plasticity of Materials from the Standpoint of the Load-Carrying Capacity of Structure*") published by the Royal Hungarian University Press, in Budapest, Hungary, in 1942).

Other publications of Kazinczy in this field are:

"Statisch unbestimmte Tragwerke unter Berücksichtigung der Plastizität," *Der Stahlbau*, No. 5 58 (1931).

"Die Weiterentwicklung der Plastizitätslehre," *Technika*, Budapest (1931).

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TRANSLATION FROM DR. GÁBOR KAZINCZY'S ARTICLE (P. 102, VOL. 2, NO. 6, OF THE PERIODICAL *BETONSZEMLE*

Translated by N. J. Hoff

It is of interest that after collapse the beam was bent at the supports where the stresses in the steel were below the yield point of the material according to the analysis. This circumstance also proves that a clamped steel girder can deflect catastrophically only when the stress in three of its sections is at least as large as the yield stress. These sections must be imagined to be provided with hinges; if a girder whose two ends are rigidly fixed is provided with only two hinges, its load carrying capacity is not exhausted because the portion between the hinges acts as a simply supported girder, and the portions outside the hinges as cantilevers. When, however, three hinges appear, motion will take place. Naturally these hinges are not real. It is known from tensile tests that steel has a so-called yield stress; at this stress steel stretches materially with the load remaining approximately constant; hence the curvature of a beam can increase for a while under a constant bending moment, and the moment must be increased only after a certain curvature has developed. (We wish to remark that this statement is not quite exact because the moment must be increased continuously, but very slowly.) This means that a clamped steel beam would be ready to distort when the yield stress is reached in its end section, or in its center section, but motion cannot take place in accordance with the principle stated. What will now happen if the loading is increased? The sections in question would be able to support increased moments only if a certain amount of curvature developed, but this curvature cannot develop. Consequently under additional loads the beam will behave as if the sections in question were provided with hinges, that is in these sections the moments will remain the same as they were at the time the yield point of the steel was reached (the moments increase only by negligible amounts). The loading can be increased until the yield point is reached in a third section and only then will motion take place.

But this shows that the degree of fixity of the ends is immaterial.

If a load is given for which a steel girder must be proportioned, we select a trial section and calculate the moment that can be supported in the middle of the girder. We leave the remainder of the moment for the end section; if this remaining moment causes a stress smaller than the yield stress, the steel beam cannot collapse.

Therefore, a steel beam not embedded in concrete should not be proportioned for a moment of $(wL^2/12)$ but for a moment of $(1/2)(wL^2/8) = (wL^2/16)$ even if the ends of the beam can rotate a certain amount, whatever that amount may be; because, as has already been pointed out, the important thing is to have a factor of safety of two against yielding, and not to insure that the maximum stress under the prescribed load is less than one-half the yield stress (1200 kg per sq cm).

Ductility Transition of Weld Metal

Ductility transition of various type weld metal and relative resistance to fracture initiation of weld metal and structural steels

by W. S. Pellini and E. W. Eschbacher

Abstract

The ductility transition characteristics of various types of weld metal were determined by the drop weight test method and correlated to Charpy V and Keyhole transition data. It is shown that the initiation of brittle fracture from a sharp, cracklike flaw does not require plastic deformation of the weld metal below a critical temperature while above this temperature extensive deformation may be developed without fracture. The subject temperature is defined as the nil ductility transition. The various welds investigated developed transitions ranging from 40 to −60° F (as deposited); transitions as high as 90° F were obtained for stress relieved E12016 welds of the Ni-Mo-V type which are subject to vanadium carbide precipitation. The relative resistance to fracture initiation of weld metal and of structural steels is compared and discussed in relation to the problem of brittle failures.

INTRODUCTION

IT HAS been recognized that development of sharp, cracklike flaws during fabrication or in the course of service of welded structures provides the "trigger" elements required for the initiation of brittle failures. Whether or not the presence of such trigger elements actually results in the initiation of a brittle failure is determined by the properties of the material in which the notch is located, the temperature range of service and the loading conditions. If the material retains the ability to deform in the presence of the notch flaws at the lowest service temperature, fractures will not initiate in structures which are loaded within the elastic range. That is to say, the stress level is of no importance as long as it is kept below the range of plastic deformation, which is the usual case. On the other hand, if the material containing the notch loses its ability to deform in the presence of the sharp notch flaws at service temperatures, fracture initiation becomes possible and design factors related to levels of nominal elastic loading then become important.

The development of cracks in arc craters, heat-affected zones and/or welds may be considered to represent a process of notching in the same sense that a notch is imposed by machining or other means. Unfortunately, the natural notching process produces the sharpest possible types of notches (cleavage cracks) and therefore the most critical with respect to service performance.

In laboratory investigations it is important to determine the effects of such sharp notches by methods which actually produce the natural type. Previous investigations at this Laboratory[1, 2] have demonstrated the effects of cracklike notches on the performance of structural and alloy steels. These studies were concerned with fracture initiation under conditions such that a crack fault projected into the base metal. An example of this condition in service is that of a HAZ crack which is oriented so as to project into the contiguous base metal.

The present investigation is concerned with fracture initiation in welds resulting from the presence of crack flaws located entirely in weld metal. The relative resistance to initiation of brittle fractures for various types of weld metal is determined and compared with the previously established characteristics of structural steels.

It should be emphasized that this and the previous investigation are not concerned with the actual level of elastic loading required to initiate fracture but rather with determining the *boundary* temperature above which plastic deformation is required for the initiation of fractures. At temperatures above the boundary temperature the fracture initiation problem for structures which are loaded only within the elastic range is considered solved by material properties. At temperatures below the boundary temperature design factors related to the actual level of elastic loading become important.

The drop weight test was used to determine the above described boundary temperature for various types of weld metal. In addition Charpy V and Keyhole transition curves were obtained in order to establish possible correlation with the fracture data.

PROCEDURES

The drop weight test entails impact loading of a specimen featuring a crack starter weld (brittle, hard-surfacing type), Fig. 1. Briefly, the crack starter weld develops a cleavage crack when the bend deformation reaches 3 deg (incipient yielding) and the additional 2 deg of bend allowed by the stop provides a test of the ability of the metal to develop deformation in the presence of the extremely sharp notch. The highest temperature of fracture in this test is termed the drop weight nil ductility transition temperature (DWT) and is considered to represent the boundary temperature as described above.

The drop weight test specimen developed for weld studies is shown in Fig. 2. The initiation and propagation of fracture is restricted entirely to a conventional multipass butt weld; in this respect the prime plate serves only as the "grip." However, the effects of the prime material with respects to weld dilution were part of the investigation. Because of the small amount of bending developed in this test, precautions were taken to eliminate specimens which showed visual evidence of camber or distortion.

Charpy V and keyhole specimens were also obtained as indicated in Fig. 2. Each specimen was etched lightly to ensure that the notch and fracture regions were contained entirely in weld metal.

Tables 1, 2 and 3 list analyses of the plate materials and welds; also, the welding conditions for each type of weldment.

RESULTS OF DROP WEIGHT TESTS

The results of two typical drop weight test series are shown in Fig. 3*A* and Fig. 3*B*. The sharp transition in a 10° F step typical of rolled steels was not obtained for the weld metal; usually, a scatter of 10 to 20° F was encountered, as illustrated in the figures. For this reason four to six

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Presented at the AWS National Fall Meeting at Cleveland, Ohio, Oct. 20, 1953.

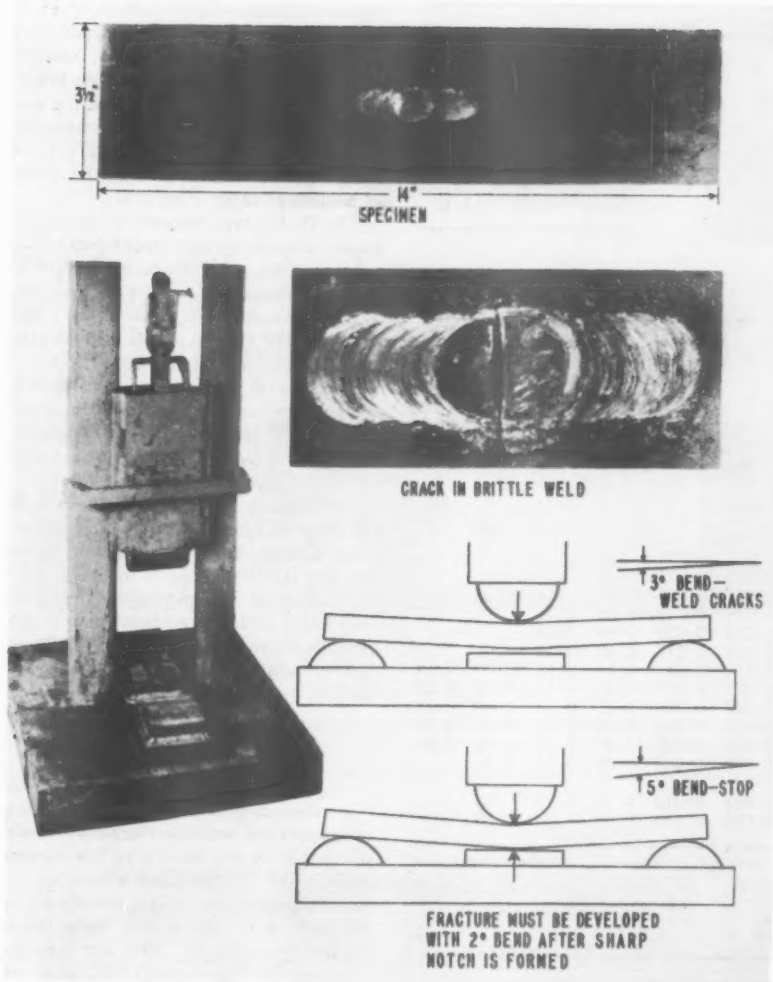

Fig. 1 Drop weight test method. The brittle weld is notched with a rotating abrasive disk to facilitate cracking. Note weld crack in specimen which resisted fracture

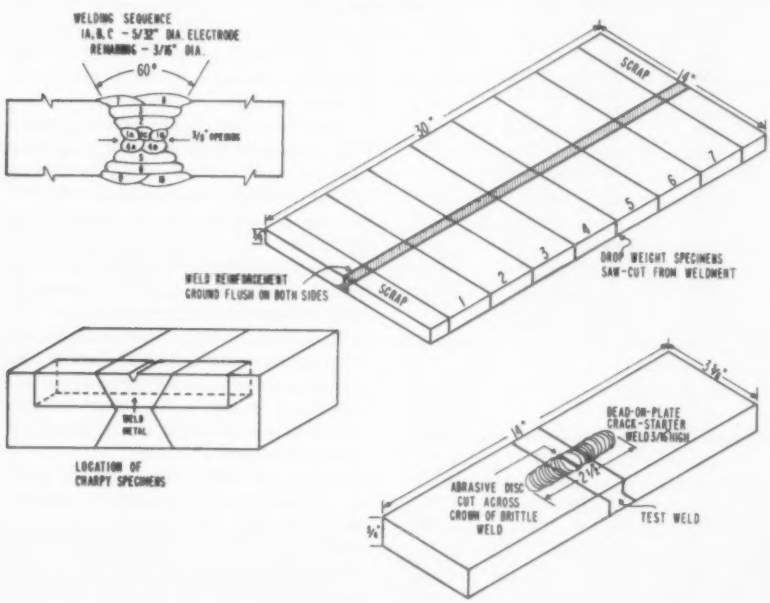

Figure 2

specimens were tested at each temperature in the critical range and the DWT was taken as the temperature range over which scatter developed. Two possible reasons are advanced to explain the difference in behavior of weld metal as compared to rolled steels:

1. Variability in weld metal properties (also shown in greater scatter observed in Charpy tests).
2. Small variations in the flatness of the drop weight specimens.

At temperatures 20° F or more above the scatter range the weld metal is capable of withstanding relatively drastic deformation despite the presence of the sharp cleavage crack developed by the brittle weld. This is illustrated by the "increased deformation" tests of the E6010 weld series of Fig. 3*A*. These tests were conducted by removing the stop and using various heights of drop to develop the desired level of deformation. A similar behavior has been demonstrated previously for structural steels.[2] The transition from high to nil ductility which is developed over a relatively narrow temperature range is the significant feature of the boundary temperature concept.

Figure 4 summarizes the test results; the bands indicate the scatter range—no fractures were obtained at temperatures above the band and no specimens resisted fracture below the band.

The E6010, E6020-30 and E7016 welds develop nil ductility in the presence of a sharp notch (DWT) in the range of −10° F to +20° F. It is noted that moderate peening of the last pass raises the highest temperature of fracture of the E6010 type approximately 40° F. The E6012 weld appears to be inferior to the E6010 type as indicated by DWT of 30 to 40° F. The dilution effects of the base plate (SK vs. FK) are considered to be either minor or not significant (10° F).

The E8016 type (nickel bearing G180 Mil Spec) develops DWT in the range of −10 to −30° F. The difference due to the base steel (ABS-B vs. HTS) is not considered significant.

The Ni-Mo-V, E10016 type (Grade 230 Mil Spec), develops DWT in the range of −50 to −70° F, and the Ni-Mo-V, E12016 type (Grade 260 Mil Spec), falls in the range of −60 to −70° F. These two electrodes appear to be essentially equivalent. Only the Grade 230 type shows minor, and probably not significant, effects due to the base plate despite the fact that a relatively high-alloy steel and a structural mild steel are included in the comparison. Stress relieving for 2 hr at 1150° F results in drastic embrittlement of both welds; the DWT is raised 110° F for G230 weld and 150° F for the G260 weld. This embrittlement has been deduced previously[3] to be due to vanadium carbide precipitation. The more pronounced embrittlement noted for the Grade 260 type is probably due to its

Table 1—Plate Analyses

Type	*Code*	*C, %*	*Mn, %*	*Si, %*	*Ti, %*	*V, %*	*Ni, %*	*Cr, %*
Semikilled MS	SK	0.24	0.57	0.05	..	..		.. ..
Fully killed MS	FK	0.16	0.67	0.21	..	..	..	..
Ship plate ABS-B Spec.	ABS-B	0.18	0.69	0.04	..	..	..	..
Navy high tensile	HTS	0.19	1.21	0.26	0.01	0.03	..	..
High alloy	HA	0.27	0.29	0.24	..	..	3.12	1.19

All $^3/_4$-in. thickness plates.

Table 2—Weld Analyses

Electrode	*Plate*	*C, %*	*Mn, %*	*Si, %*	*S, %*	*P, %*	*Ni, %*	*Cr, %*	*Mo, %*	*V, %*
E6010										
(A46)*	FK	0.06	0.65	0.34	0.024	0.020	..	..	..	..
(A52)	FK	0.10	0.46	0.13	0.027	0.021	..	..	..	..
(A53)	FK	0.08	0.40	0.10	0.025	0.023	..	..	..	..
(A53)	SK	0.08	0.38	0.11	0.024	0.020	..	..	..	..
(B53)	SK	0.09	0.61	0.25	0.029	0.025	..	..	..	..
(C53)	SK	0.09	0.41	0.20	0.024	0.012	..	..	..	..
E6012	FK	0.07	0.29	0.20	0.031	0.022	..	..	..	..
E6020–30	SK	0.12	0.30	0.15	0.025	0.021	..	..	..	..
E7016	HA	0.10	0.45	0.43	0.027	0.023	0.40	0.18	..	..
	ABS-B	0.10	0.47	0.53	0.028	0.024	0.05	0.03	..	..
E8016-G180	HTS	0.07	0.57	0.58	0.024	0.020	0.88	0.14	..	..
	ABS-B	0.08	0.35	0.57	0.021	0.017	0.86	0.14	..	..
E10016-G230	HA	0.06	0.47	0.43	0.018	0.014	1.54	0.15	0.38	0.14
(Ni-Mo-V)	FK	0.05	0.50	0.48	0.024	0.010	1.31	0.19	0.35	0.13
	HTS	0.06	0.52	0.48	0.020	0.016	1.47	0.24	0.41	0.13
E12016-G260	HTS	0.06	0.87	0.34	0.018	0.012	1.33	0.13	0.53	0.20
(Ni-Mo-V)	HA	0.07	0.90	0.40	0.022	0.018	1.53	0.23	0.42	0.20
E10015 (Mn-Mo)	HTS	0.13	1.81	0.40	0.030	0.026	0.09	0.14	0.21	..
Cr-Mo	HA	0.08	0.54	0.31	0.024	0.010	0.38	1.77	0.53	..
	HTS	0.07	0.61	0.30	0.025	0.010	0.05	1.87	0.50	..

* A, B, C. Various brands. 46, 52, 53 = year of purchase; all other electrodes '53 purchases.

Table 3—Welding Conditions*

Electrode class	*Size electrode, in.*	*Amp*	*Volt*
E6010 (All)	$^5/_{32}$	150	24–26 DCRP
	$^3/_{16}$	200	26–28 DCRP
E6012	$^5/_{32}$	150	20–22 DCSP
	$^3/_{16}$	200	22–24 DCSP
E6020–30	$^5/_{32}$	150	26–30 DCRP
	$^3/_{16}$	200	28–32 DCRP
E7016	$^5/_{32}$	150	22–24 DCRP
	$^3/_{16}$	250	22–24 DCRP
E8016 (G180)	$^5/_{32}$	150	22–24 DCRP
	$^3/_{16}$	250	22–24 DCRP
E10016 (G230)	$^5/_{32}$	150	22–24 DCRP
	$^3/_{16}$	250	22–24 DCRP
E12016 (G260)	$^5/_{32}$	150	22–24 DCRP
	$^3/_{16}$	250	22–24 DCRP
E10015(Mn-Mo)	$^5/_{32}$	150	22–24 DCRP
	$^3/_{16}$	250	22–24 DCRP
Cr-Mo	$^5/_{32}$	150	22–24 DCRP
	$^3/_{16}$	250	22–24 DCRP

* All 200° F preheat and interpass.

Table 4

Weld	*—Keyhole energy,— 60°F*	*0°F*	*−40°F*	*DWT, ° F*	*—Keyhole, ° F— Δt**	*15 ft-lb*	*Δt**
Cr-Mo (HTS)	33	33	29	−10 to 0	..	−90	..
G180 (ABS-B)	43	43	41	−30 to −10	−10°	−120	−30
G260 (HTS)	33	33	30	−70 to −60	−60°	−160	−70

* Δt = Difference in transition temperatures referenced to Cr-Mo type.

higher vanadium content (0.20 vs. 0.13%).

The Mn-Mo, E10015 type appears to be equivalent to the Ni-Mo-V E10016 and E12016 types as evidenced by a DWT of −60 to −70° F. Stress relieving appears to have a minor effect as compared to the Ni-Mo-V types; the DWT is raised approximately 20° F as the result of holding at 1150° F for 2 hr.

The Cr-Mo type appears to be significantly affected by base metal dilution as evidenced by a difference in the DWT range of approximately 20° F between the HTS and the high-alloy base steels. The −10 to +20° F range of this weld metal is equivalent to that of the E6010 type.

The general relationship of the DWT temperature range to Charpy V transition curves is illustrated by the representative curves presented in Fig. 5. In most cases, there was a correlation between the DWT range and the Charpy V 15 to 25 ft-lb temperature range. A similar correlation with Charpy keyhole transition curves was not possible as shown in Fig. 6. As in the case of structural steels[1, 2] direct correlation with the keyhole curve is not possible because the DWT range falls on the essentially flat region of the upper shelf.

GENERAL DISCUSSION

Previous drop weight test investigations of rimmed and semikilled structural steels of the ABS-A ship plate type have shown that the DWT is developed without exception at temperatures which correspond to the Charpy V 3 to 10 ft-lb range (most frequently 5–8 ft-lb). This has been interpreted to signify that the sharpest cracks which may be present *in the steel* of a welded structure which is loaded elastically should not initiate fracture at temperatures above the Charpy V 10 ft-lb transition for the steel. This follows from the boundary temperature concept that extensive deformation is required for fracture initiation at these temperatures.

The NBS investigation[4] of ship fracture steels showed that plates which originated fractures where characterized by Charpy V values which never exceeded 11 ft-lb (average 5 to 8 ft-lb) at the temperature of fracture. Thus, direct correlation with service experience also indicates that a nil ductility transition (boundary temperature) at approximately the Charpy V 10 ft-lb transition. These data indicate that the drop weight test correctly predicts the boundary temperature below which the presence of sharp cracks becomes highly critical to the performance of elastically loaded structures.

The actual DWT temperatures determined from the investigation of approximately 50 ship plate steels, including material removed from fractured ships (ABS −A type), ranged from 0 to 60° F with a majority of values at 20 to 40° F. These findings are in agreement with service ex-

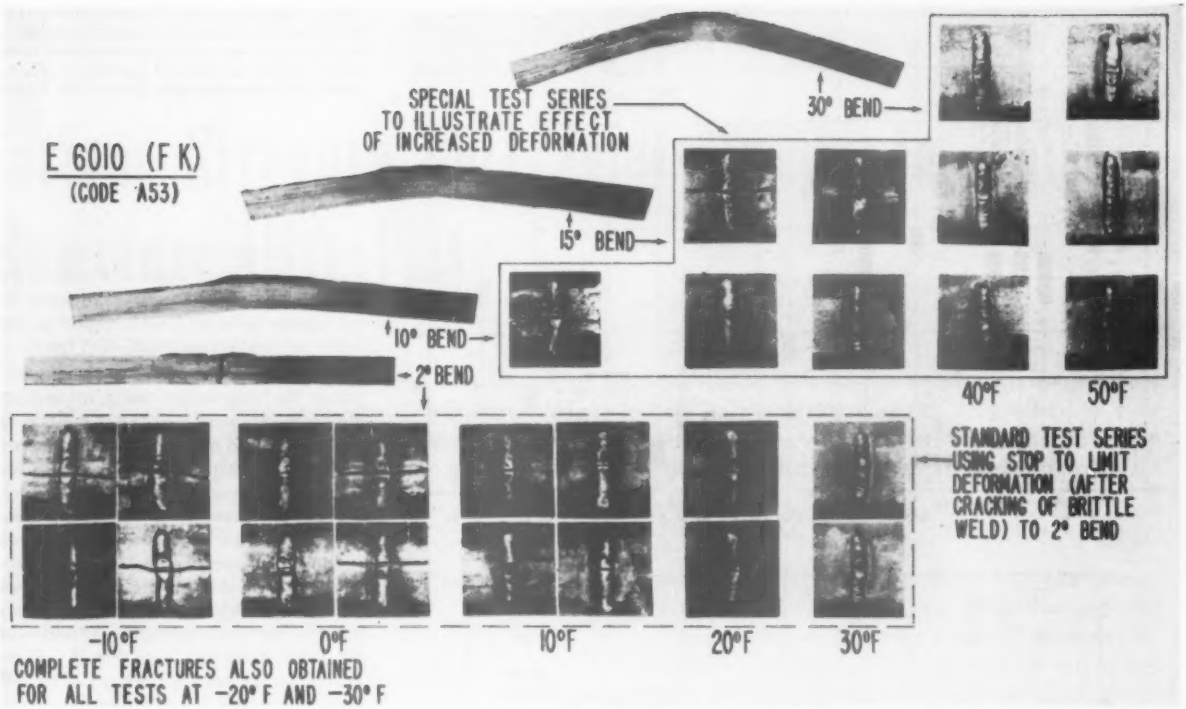

Fig. 3A Illustrating the critical effect of temperature on the ability of the weld metal to develop plastic deformation in the presence of a sharp cracklike notch

The DWT range for this weld is −10 to 0° F; all specimens of the standard test series resisted fracture above 0° F and no specimens resisted fracture at −10° F and below.

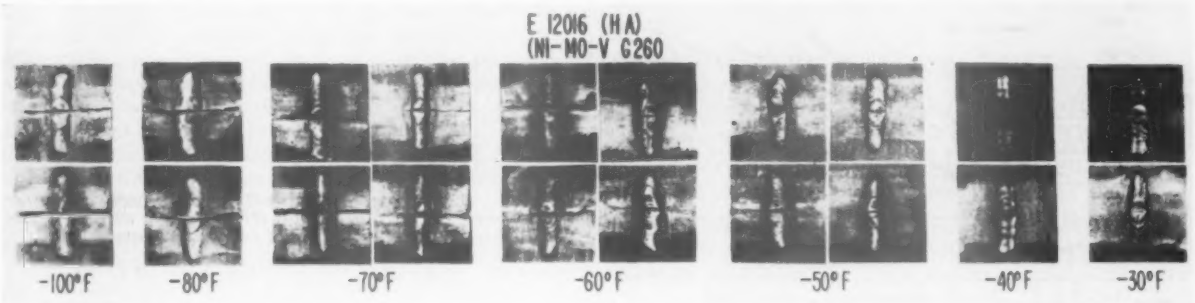

Fig. 3B Standard test series for weld metal of high notch toughness. Fracture is resisted to −60° F; DWT range −60 to −70° F

perience in that temperatures below 60° F are critical to ship performance.

While ship fractures originated in the proximity of welds (regions where flaws should be expected), it was only in exceptional cases (welds of extreme partial penetration type) that fractures propagated even a few inches in the weld *per se*. Actually, welds stopped fractures in a number of cases which was far out of proportion to the amount of weld metal compared to steel in the path of fracture.[4]

The results of drop weight tests for E6010 weld metal as compared to semikilled and rimmed structural mild steels indicate that the weld metal is more resistant to fracture initiation than the steels. The drop weight data show that E6010 weld metal develops nil ductility in the presence of sharp cracks at temperatures in the range of +20 to −10° F while ABS-A steels develop nil ductility in the range of 0 to 60° F. This strongly suggests that the initiation of ship fractures (at least the majority which occurred at temperatures in the range of 30 to 50° F) was due to a notch ductility deficiency of the steel rather than of the weld metal. If this conclusion is accepted, it is indicated that improvements of the notch ductility of the steel are of greater importance and necessity than improvements of the weld metal.

A consideration of the case opposite to the one described above, for example a E6010 butt weld in a steel having a low DWT (such as −60 to −100° F) is of interest. Explosion Bulge tests[2] have demonstrated that for combinations such that the notch toughness of the weld is markedly inferior to the steel the initiation and propagation of brittle fractures takes place entirely in the weld. In such cases the bulged weldments split apart in the weld and the plate portions show no sign of fractures except short tears of shear type. The use of welds and steels which resist fracture initiation to temperatures at least as low as the lowest service temperature should be considered of equal importance inasmuch as cracklike flaws may be present in both the weld and base plate. In other words, the nil ductility transition (boundary temperature) of both the weld and the steel should be below the lowest operating temperature. The drop weight data can serve as a guide in this respect.

The Charpy V 5 to 8 ft-lb transition temperature which has been demonstrated to be a reliable index of the highest temperature of nil ductility in the presence of sharp crack for rimmed and semikilled structural steels does not hold for weld

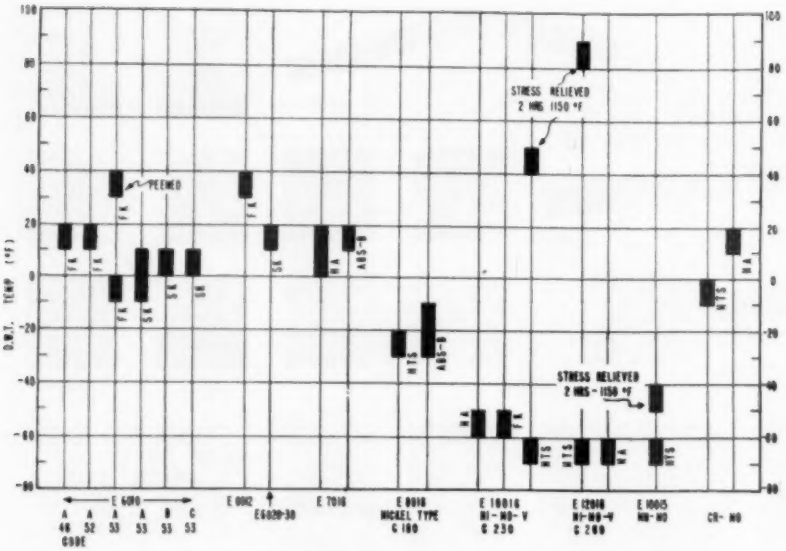

Fig. 4 Summary of drop weight tests. The band indicates the scatter region; no fractures obtained at temperatures above the band and all specimens fractured at temperatures below the band

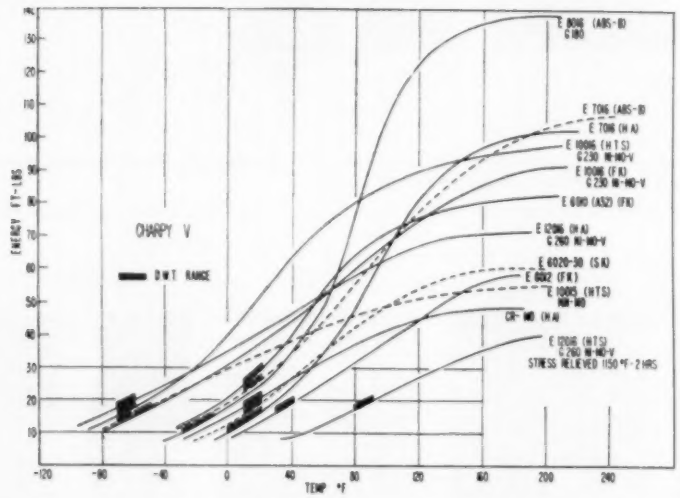

Fig. 5 Illustrating the general correlation of DWT range with Charpy V transition curves

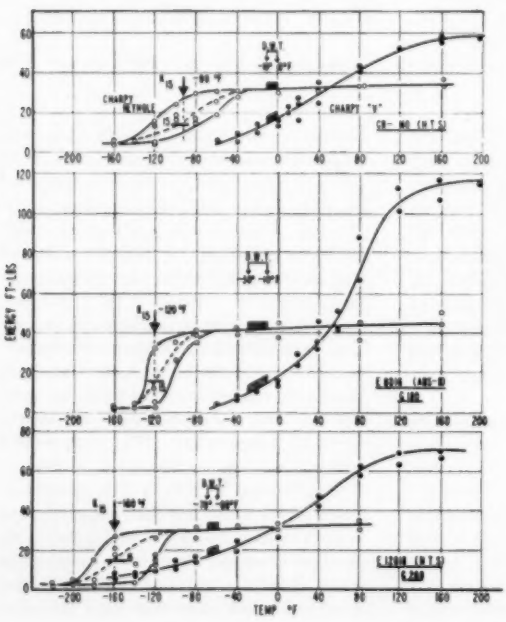

Fig. 6 General relationship of Charpy V, Charpy keyhole and drop weight transition data

metal. A range of 15–25 ft-lb appears to provide the proper index for welds. In general, Charpy V data for weld metal do not appear to be as discriminating as was found for rimmed and semikilled steels.

Based on the experience of this investigation the drop weight test is a considerably less expensive and faster method of evaluating weld metal than either Charpy V or keyhole tests conducted so as to obtain a transition curve. The common "short-cut" practice of evaluating weld notch toughness by Charpy keyhole tests conducted at specific single temperatures such as RT, 0 or −40° F does not appear to discriminate between welds of widely different resistance to fracture as indicated by Table 4 derived from Fig. 6. Comparison on the basis of the keyhole 15 ft-lb transition places the welds in the correct order, however, in many cases the scatter obtained with the keyhole tests precluded drawing a significant curve for the determination of the 15 ft-lb temperature.

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Fatigue Strength Butt Joints in $^3/_8$-In. Thick Aluminum Alloy Plates

The fatigue strength of butt-welded joints for cycles greater than a million are approximately the same regardless of the alloy. For higher stresses involving less than 1000 cycles to failure, the fatigue strengths are approximately equal to the static butt-weld strengths

by E. C. Hartmann, Marshall Holt and I. D. Eaton

Synopsis

This paper gives results of direct-stress fatigue tests, made at Alcoa's Aluminum Research Laboratories, on welded butt joints in $^3/_8$-in. thick aluminum alloy plates. It is shown that there is little difference in the fatigue strengths of joints in 3S, Alclad 14S, A54S and 61S plates for fatigue lives greater than 10^6 cycles. On the other hand, for fatigue lives less than 10^4 cycles, the fatigue strengths rank in the same order as the static tensile strengths of the welded joints. The fatigue strength of a plate with an appurtenance attached with a fillet weld is practically the same as that of a butt-welded joint. On the basis of nominal stress on the gross section and fatigue lives within a certain range of cycles, the fatigue strengths of riveted butt joints are within the band of results for welded butt joints.

INTRODUCTION AND OBJECT

An earlier paper[1] based on data obtained at the Aluminum Research Laboratories of the Aluminum Company of America indicated the effects of geometry or design on the static and fatigue strengths of arc-welded joints in $^3/_8$-in. thick aluminum alloy plate. Although aluminum alloy 61S-T6* was used for the 14 joint types of these earlier tests, it is reasonable to believe that the principles developed apply generally to joints of other structural metals. A few additional static and fatigue tests on arc-welded joints in $^3/_8$-in. thick 3S-F aluminum alloy plate have been published in Reference 2. Aluminum Research Laboratories has continued the fatigue testing of welded joints in an effort to keep abreast of current welding techniques and interest in weldable alloys. It is the purpose of this paper to discuss the static and fatigue test results accumulated to date on welded butt joints made in plates of a number of commercial aluminum alloys, with various weld methods, and with several weld wires. The paper presents results from more than 200 tests on arc-welded 61S-T6, A54S-H34, Alclad 14S-T6 and 3S-F aluminum alloy plates fabricated by four welding techniques. Comparison is made of the static and fatigue strengths of arc-welded joints with static and fatigue strengths of riveted double-strap butt joints.

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* Formerly designated 61S-T.

MATERIAL AND SPECIMENS

Mechanical properties of the aluminum alloy plates used in these tests are listed in Table 1. The values compare favorably with published values for the various materials and it can be seen that they meet their respective specification requirements. The $^3/_8$-in. thick aluminum alloy plates were welded into panels from which the individual test specimens were taken. A typical pair of panels, from which specimens for a single series of tests could be obtained, is shown in Fig. 1. In a few cases, one large welded panel was prepared rather than a pair of the small ones shown.

The welding procedure used with the 14 combinations of alloy, weld wire and specimen type are given in Table 2, each combination being identified with an item number. The flux-coated metal electrode, the inert-gas metal (tungsten) arc, and the automatic carbon-arc methods of fabrication are described in Reference 3 under the headings Metal-Arc Welding, Tungsten-Arc Welding and Carbon-Arc Welding, respectively. Briefly, the semiautomatic inert-gas metal arc method is a manual welding method in which the weld wire is used as the electrode and is fed automatically through an inert-gas shield. Most of the panels were prepared by the Alcoa Process Development Laboratories, New Kensington, Pa.

All welds were made by qualified welders using standard commercial equipment and standard techniques. Thus, some of the plates were preheated prior to weld-

Table 1—Mechanical Properties[a] of Materials Used in Specimens for Fatigue Tests of 3/8-In. Thick Arc-Welded Aluminum Alloy Plates

	Alloy and temper	*Tensile strength, psi*	*Yield strength,[b] psi*	*Elongation in 2-in., %*	*Item No.[c]*
	61S-T6[d]	46,300	40,250	17.9	1, 2
	61S-T6	43,350	38,150	14.2	3
	61S-T6	43,450	37,450	16.0	4
	61S-T6	43,130	35,630	16.6	9, 10
Specified minimum value[e]	61S-T6	42,000	35,000	10.0	
	A54S-H34	42,770	31,330	18.3	5–7, 9, 10
	A54S-H34	41,550	31,180	18.9	8
Specified minimum value[f]	A54S-H34	37,000	27,000	10.	
	Alclad 14S-T6	67,200	61,000	13.0	11
Specified minimum value[g]	Alclad 14S-T6	64,000	57,000	8.0	
	3S-F	23,520	21,920	18.1	12
	3S-F[e]	22,800	17,400	27.5	13, 14
Specified minimum value[g]	3S-H14	20,000	17,000	6	

[a] Tests determined on standard rectangular test specimen: see Fig. 6 of ASTM Spec. E8–52T, *1952 Book of ASTM Standards*, Pt. 2 p. 1211. Values listed represent average of several test results.
[b] Stress at offset of 0.2%; Templin autographic extensometer (× 500).
[c] Item number refers to items of welded panels listed in Table 2.
[d] Properties previously reported in Reference 1.
[e] Properties previously reported in Reference 2.

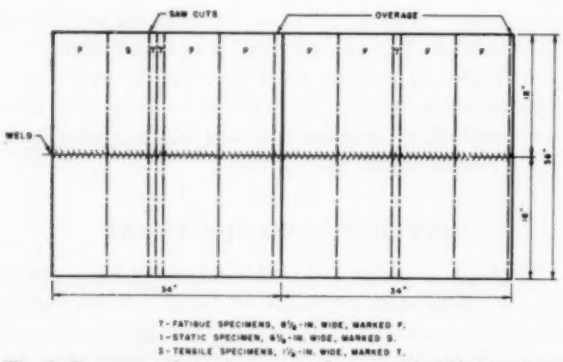


Fig. 1 Location of specimens cut from welded 3/8-in. plates

ing, whereas others were not. In some cases, parent metal was used for the weld wire, whereas in other cases a more suitable weld wire was used. Some of the welding was done as single-pass welding and some as multi-pass welding. In no case was a welded panel, nor a test specimen, reheat treated after welding.

All panels were radiographed after welding. No repair of defects was employed; rather, when an occasional discontinuity was found, the locations of the individual specimens taken from the large panels were adjusted so that the defect was cut out in machining the specimens. In a few cases, the panels were warped as a result of welding and, with the exception of the specimens of Item 4, these individual specimens were straightened by cold flattening previous to fatigue testing.

The specimens described by the letter A were tested with the weld bead intact, that is, as-welded, whereas those described by the letter B were tested after the weld bead had been dressed flush with the surfaces of the plates. Except in a few cases, the final grinding scratches were transverse to the weld bead, that is,

Table 2—Tabulation of Welding Procedure Used for Fatigue Test Panels of 3/8-In. Thick Aluminum Alloy Plate

Item no.	*Plate alloy and temper*	*Method of fabrication*	*Weld wire*	*Specimen types tested (see Table 3)*
1	61S-T6	Flux-coated metal electrode arc	43S	A1, B1, C, D
2	61S-T6	Inert-gas metal (tungsten) arc	43S	A1, B1
3[a]	61S-T6	Inert-gas metal (tungsten) arc	43S	A1, A2, A4, B2
4	61S-T6	Semiautomatic inert-gas metal arc	43S	A5
5	A54S-H34	Semiautomatic inert-gas metal arc	A54S	A3
6	A54S-H34	Semiautomatic inert-gas metal arc	56S[b]	A3, B3
7	A54S-H34	Semiautomatic inert-gas metal arc	Exp.[c]	A3
8	A54S-H34	Semiautomatic inert-gas metal arc	A54S	A5
9	A54S-H34 to 61S-T6	Semiautomatic inert-gas metal arc	A54S	A3, B3
10	A54S-H34 to 61S-T6	Semiautomatic inert-gas metal arc	Exp.[c]	A3
11	Alclad 14S-T6	Flux-coated metal electrode arc	43S	A3, B3, C
12	3S-F	Inert-gas metal (tungsten) arc	2S	A1, B1
13	3S-F	Flux-coated metal electrode arc	43S	B3
14	3S-F	Automatic carbon arc	2S	B6

[a] Items 2 and 3 are identical except that Item 3 was fabricated 3 years later.
[b] 56S weld wire is now available in improved version designated as C56S.
[c] Experimental weld wire.

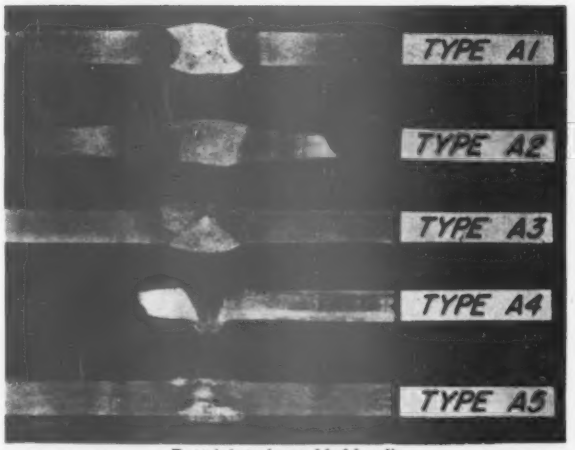
Table 3—Tabulation of Welding Details Used in Preparation of Fatigue Test Panels of 3/8-In. Thick Aluminum Alloy Plate

Specimen Types A: Plain butt-welded joint; weld bead left in as-welded condition.
- A1: Groove filled with two passes, back chipped and welded with single pass.
- A2: Single pass welded from one side, removable copper backing.
- A3: Groove filled with single pass, back chipped and welded with single pass.
- A4: Triple pass welded from one side, no backing support.
- A5: Groove filled with multiple passes, back welded with multiple passes.

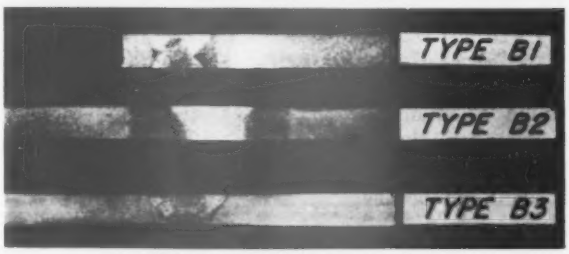
Specimen Types B: Plain butt-welded joint; weld bead removed.
- B1: Groove filled with two passes, back chipped and welded with single pass.
- B2: Single pass welded from one side, removable copper backing.
- B3: Groove filled with single pass, back chipped and welded with single pass.
- B6: Single pass welded from one side.

Specimen Type C: Solid main plate; attachment plate normal to main plate; tack welded then single pass fillet welded each side of attachment (see Fig. 2).

Specimen Type D: Solid main plate; attachment plate parallel to main plate; assembly clamped to steel angle, single pass fillet welded each edge of attachment (see Fig. 2).



Butt joints (as-welded bead)



Butt joints (weld bead removed)

Fillet-welded attachments

Fig. 2 Sections of welded specimens

parallel to the load line during the test. Variations in welding procedure as described in Table 3 are identified by the numeral suffixed to the letter.

For comparison, specimens described by the letters C and D were made in which an appurtenance in the form of 2- and 4- in. wide plates, respectively, were attached by fillet welds to a continuous main plate. Unlike the weld in the butt joints, the weld in these cases did not transmit the applied load. In the specimens of Type C, the auxiliary plate was normal to the main plate; hence, the heels of the fillet welds were only 3/8 in. apart. In the specimens of Type D, the auxiliary plate was flat against the main plate, the heels of the fillet welds being 4 in. apart.

Typical cross sections of the welds are shown in Fig. 2. The amounts of porosity and other defects shown are within the tolerances of Section VIII of the ASME Boiler and Pressure Vessel Code (Par. UW-52 (e)).

The location of the individual specimens within the welded panels is indicated in Fig. 1. The fatigue specimens, marked *F*, were machined to conform to the dimensions shown in Fig. 3. Some of the fatigue specimens were tested with the test section 2 to 3 1/2 in. wide, rather than 5 in. as shown, in order to obtain higher stresses within the capacity of the fatigue machines. The static specimens, marked *S*, were machined on both edges to give straight and parallel sides and a width of about 5 7/8 in.

The strips, marked *T*, served a dual purpose. From each end of the strip, far removed from the weld zone, standard tensile specimens were taken to determine the mechanical properties listed in Table 1. The central portion of each strip, containing the weld, was used to obtain additional static-test data to supplement the result on the wider (5 7/8-in.) specimen. Some of the specimens taken from the narrow strips were tested as full-section tensile specimens, that is, with the weld bead left in the as-welded condition; while others were

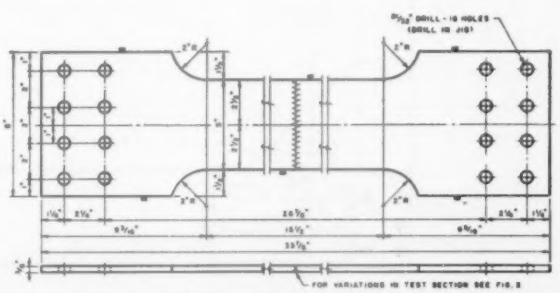


Fig. 3 Welded joint fatigue specimen

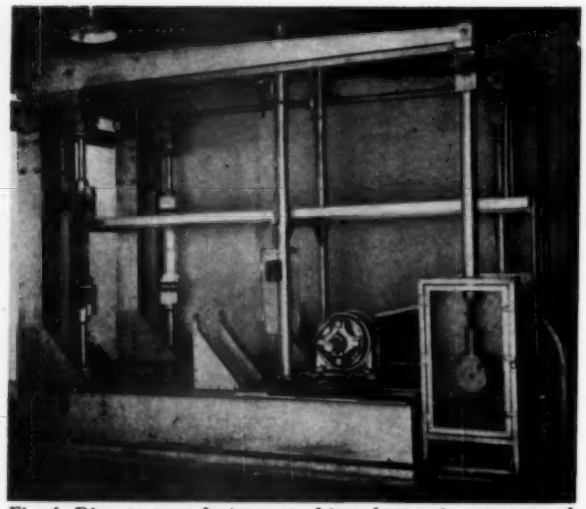


Fig. 4 Direct-stress fatigue machines for testing structural units

tested as reduced-section tensile specimens, that is, with the weld bead dressed flush with the main plates. In all cases, the edges of the specimens were machined straight and parallel.

METHOD OF TESTING

The static tests were made in one of several universal testing machines at the Aluminum Research Laboratories (ranging from 20,000 to 300,000 lb capacity). Periodic calibration of the testing machines showed that they meet the ASTM and Government requirements for accuracy.

The direct-stress fatigue tests reported in this paper were made in the Aluminum Research Laboratories' Structural Fatigue Testing Machines. A pair of these machines, which were designed especially for this kind of work and which are described in detail in Reference 4, are shown in Fig. 4. Noted on the schematic drawing of one unit of these machines, shown in Fig. 5, are the principal functional components of the machine and an outline of the fatigue test procedure. Although these machines were constructed for applying a load involving either tension, compression, or both; tests discussed in this paper were made with a tensile stress range from 0 to a maximum (stress ratio = 0). The loading fixtures, designed by R. L. Templin, incorporate steel drill-rod "keys" which by function of the clamping force used make their own rounded keyway in the butt ends of the specimens; thus, the bolts are not subjected to shearing forces. In earlier methods of adapting $^3/_8$-in. plate specimens to these machines[1] interference-fit bolts were used to transmit the load to the specimen. This method led to occasional failures through the bolt holes in the butt ends. In a later method, however, interference keys were used and with this method of attachment very few failures associated with attachment have been encountered.

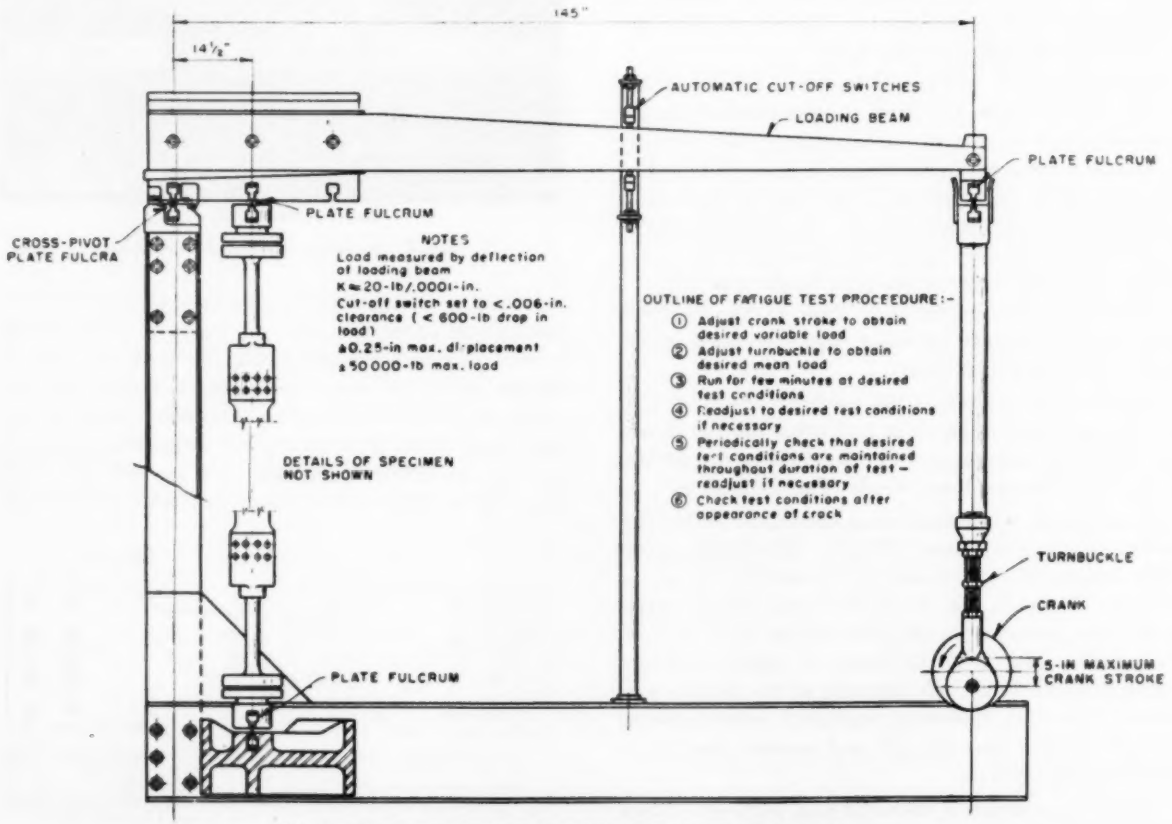

145"
14 1/2"
AUTOMATIC CUT-OFF SWITCHES
LOADING BEAM
PLATE FULCRUM
PLATE FULCRUM
CROSS-PIVOT PLATE FULCRA
NOTES
Load measured by deflection of loading beam
K = 20-lb/.0001-in.
Cut-off switch set to < .006-in. clearance (< 600-lb drop in load)
±0.25-in max. displacement
±50 000-lb max. load
OUTLINE OF FATIGUE TEST PROCEEDURE:-
① Adjust crank stroke to obtain desired variable load
② Adjust turnbuckle to obtain desired mean load
③ Run for few minutes at desired test conditions
④ Readjust to desired test conditions if necessary
⑤ Periodically check that desired test conditions are maintained throughout duration of test – readjust if necessary
⑥ Check test conditions after appearance of crack
DETAILS OF SPECIMEN NOT SHOWN
TURNBUCKLE
CRANK
5-IN MAXIMUM CRANK STROKE
PLATE FULCRUM

Fig. 5 Structural fatigue testing machine set up for plate test

Table 4—Results of Static Tests on Plain Butt Arc-Welded 3/8-In. Thick Aluminum Alloy Plate

Item no.	Plate alloy and temper	Specimen type[a]	5 to 6-in. wide specimen: Tensile strength[b] psi	5 to 6-in. wide specimen: Joint efficiency,[c] %	1/2 to 2-in. wide specimen: Tensile strength,[b] psi	1/2 to 2-in. wide specimen: Joint efficiency,[c] %
1	61S-T6[d]	A1	26,700	58	24,685	53
1	61S-T6[d]	B1	23,400	51	24,270	52
2	61S-T6	A1	25,500	55	25,650	55
2	61S-T6	B1	24,600	53	23,450	51
3	61S-T6	A1	26,300	61	26,400	61
3	61S-T6	B2	26,100	60	25,350	58
3	61S-T6	A4	27,250	63	26,850	62
3	61S-T6	A2	26,000	60	25,400	59
4	61S-T6	A5	30,700	71	31,850	73
Avg.	61S-T6		26,290	59	25,980	58
5	A54S-H34	A3	36,950	86	36,400	85
6	A54S-H34	A3	38,270	90	36,100	84
7	A53S-H34	A3	37,200	87	34,700	81
8	A54S-H34	A5	40,010	96	38,000	92
Avg.	A54S-H34		38,110	90	36,300	86
9	A54S-H34 to 61S-T6	A3	29,540	68	28,300	66
10	A54S-H34 to 61S-T6	A3	29,970	69	28,500	66
Avg.	A54S-H34 to 61S-T6		29,760	68	28,400	66
11	Alclad 14S-T6	A1	32,800	49	30,000	45
11	Alclad 14S-T6	B1	35,300	53	37,000	55
Avg.	Alclad 14S-T6		34,050	51	33,500	50
12	3S-F	A1	16,590	71	...	...
12	3S-F	B1	16,870	72	...	...
13	3S-F	B3	18,410	81	19,400[e]	85
14	3S-F	B6	17,930	79	17,600[e]	77
Avg.	3S-F		17,450	76	18,500	81

[a] Specimens types defined in Tables 2 and 3.
[b] Ultimate load divided by the gross area of the main plate.
[c] Efficiency is defined as the ratio of the tensile strength of the joint to the tensile strength of the parent material as given in Table 1.
[d] Published in Reference 1.
[e] Published in Reference 2.

The machines had been previously calibrated both statically and dynamically and the inertia effects of the moving parts on the indicated load were determined. Corrections obtained from the dynamic calibrations have been included for all the fatigue tests reported herein. One pair of these machines operates at a speed of 210 cpm and the other pair at a speed of 250 cpm. The fatigue tests were considered completed at failure or at the end of about 25 million cycles even though no failure had occurred.

TEST RESULTS AND DISCUSSION

The results of the static tensile tests are given in Table 4. Included in the table are joint efficiencies based on the tensile strength of the applicable parent plate. It can be seen that the results obtained with the narrow specimens taken from the tensile strips are in good agreement with the results obtained for the wide static specimens. The weldments fall in the following decreasing order of static strengths: A54S-H34, Alclad 14S-T6, 61S-T6 and 3S-F. The joint efficiencies for the heat-treated alloys, Alclad 14S-T6 and 61S-T6, are significantly lower than those for alloys A54S-H34 and 3S-F.

Joints in which A54S-H34 plate is welded to 61S-T6 plate developed static strengths intermediate to the all-A54S-H34 and all-61S-T6 joints. When the static test results are compared with those reported by Nelson and Howell,[5] it is found that the 61S-T6 joints average slightly lower, the A54S-H34 average slightly higher, and the 3S-F joints agree very well with those reported.

The results of the direct-stress fatigue tests on arc-welded 3/8-in. thick aluminum alloy plate are plotted in Figs. 6 and 7 and in Figs. 10 through 14. The plotted points, representing results of the individual fatigue tests, indicate the maximum stress in the cycle, the minimum stress being 0 in all cases. The stresses were taken as the load divided by the gross area of the main plates and do not take into account bending stresses or high localized stresses induced by physical stress raisers.

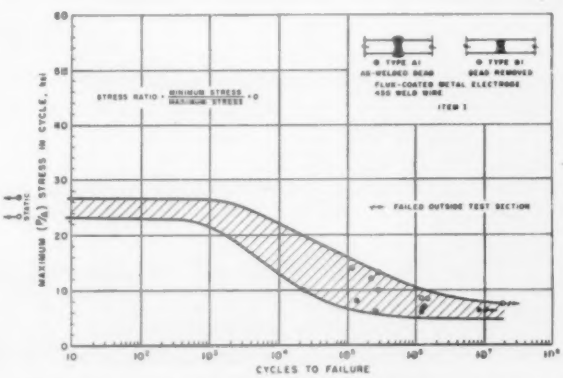


Fig. 6 Results of direct-stress fatigue tests on arc-welded 3/8-in. thick 61S-T6 aluminum alloy plate

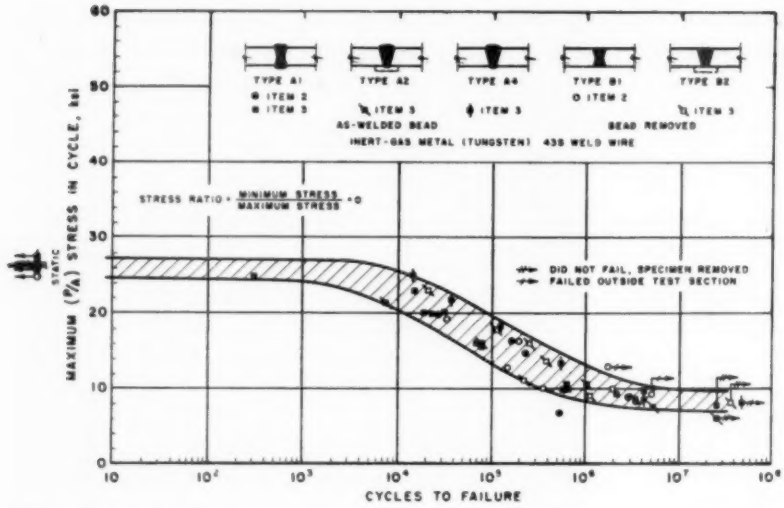


Fig. 7 Results of direct-stress fatigue tests on arc-welded 3/8-in. thick 61S-T6 aluminum alloy plate

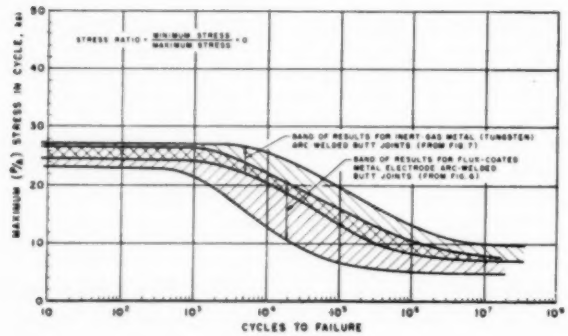

STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
BAND OF RESULTS FOR INERT-GAS METAL (TUNGSTEN) ARC WELDED BUTT JOINTS (FROM FIG 7)
BAND OF RESULTS FOR FLUX-COATED METAL ELECTRODE ARC-WELDED BUTT JOINTS (FROM FIG 6)
MAXIMUM (%) STATIC STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 8 Comparison of direct-stress fatigue test results for arc-welded 3/8-in. thick 61S-T6 aluminum alloy plate

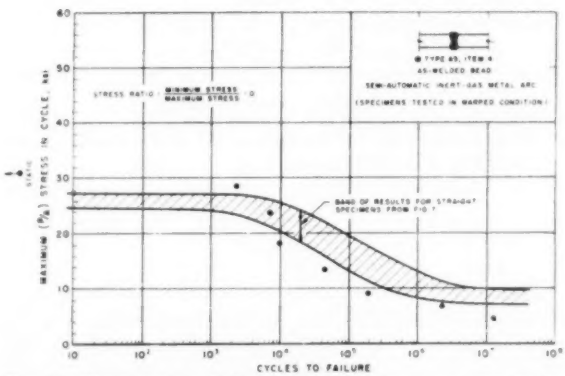

AS-WELDED BEAD
SEMI-AUTOMATIC INERT-GAS METAL ARC
(SPECIMENS TESTED IN WARPED CONDITION)
STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
BAND OF RESULTS FOR STRAIGHT SPECIMENS FROM FIG 7
MAXIMUM (%) STATIC STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 10 Comparison of direct-stress fatigue test results for arc-welded 3/8-in. thick 61S-T6 aluminum alloy plate

Flux-coated metal-electrode arc-welded joint (Item 1)

Inert-gas metal (tungsten) arc-welded joint (Items 2 and 3)

Fig. 9 Condition of weld bead for welding methods used for 61S-T6 joints

The results for the 61S-T6 joints are given in Figs. 6 through 8 and Fig. 10. The band of results in Fig. 6 includes all the data points for joints welded by the flux-coated metal electrode method. (Except for two new test results, these data were taken from Reference 1.) In drawing the bands of results shown in this paper, the static tests of the joints have been considered as one-half-cycle fatigue tests. A similar band of results for the 61S-T6 joints welded with the inert-gas metal (tungsten) arc welding method is shown in Fig. 7 where two points, one considered to be abnormally high and the other abnormally low, are not included in the band. Whereas in Fig. 6 it is seen that the fatigue-test results for the specimens in which the weld beads were removed are consistently greater than the fatigue strengths for the specimens in which the weld beads were not removed; in Fig. 7 there appears to be little, if any, consistent difference in the fatigue strengths of joints when tested in the as-welded condition or with the weld bead removed. The bands of results from Figs. 6 and 7 are compared in Fig. 8, where it can be seen that the inert-gas metal (tungsten) arc welding method produces fatigue strengths superior to those produced with the flux-coated metal electrode method. The increase in fatigue strength derived by inert-gas

metal-arc welding probably results from the greater smoothness of the weld as indicated in Fig. 9.

As previously noted, the specimens from one 61S-T6 panel welded by the semiautomatic inert-gas process (Item 4) were tested in the as-received condition in which the panels were warped as a result of the welding. The results of these tests are compared in Fig. 10 with the band of results from Fig. 7 for straight specimens. It is seen that for fatigue lives of 10,000 cycles or more, the results for the warped specimens are consistently below the band of results developed for the straight specimens. In some of the current testing of arc-welded joints, evidence can be found that the low fatigue strengths shown are caused by the warpage of the specimens. It is to be expected that, when warped specimens are tested in direct stress, bending caused by straightening the specimen in each load cycle will produce higher tensile stresses on the one surface than is indicated by the P/A stress used in analyzing these results.

Similar bands of results have been developed in Figs. 11 through 14 for the test results on joints in A54S-H34, Alclad 14S-T6 and 3S-F plates. It can be seen in Figs. 11 through 14 that, for like specimen types, the welded butt joints with the weld bead removed develop slightly higher fatigue strengths than those with the weld bead left in the as-welded condition. Figure 12 shows the bands of results for the joints in A54S-H34 plates and 61S-T6 plates as well as the individual-test results for the joints made by welding A54S-H34 plate to 61S-T6 plate. For fatigue lives greater than 5×10^4 cycles, the two bands of results nearly coincide and with the exception of two data points the results from the joints in dissimilar metals fall within the common area of the two bands.

The band of results shown in Fig. 14 for the 3S-F arc-welded joints has been developed from specimens fabricated by the following welding methods:

1. Inert-gas metal (tungsten) arc (Item 12).
2. Flux-coated metal electrode (Item 13).
3. Automatic carbon arc (Item 14).

It can be seen that the data points for dressed welds made with the inert-gas metal (tungsten) arc process (Item 12) lie in the upper portion of the band and that the fatigue strength is increased by the removal of the weld bead. It is reasonable to believe that the lower limit of the band would be lowered if data were available from as-welded specimens made by the other two methods of welding; however, the band of results as given in Fig. 14 fairly represents the data for the inert-gas metal-arc welded joints.

The bands of results for the joints in 61S-T6 and in Alclad 14S-T6 plates welded with the flux-coated metal-electrode method are compared in Fig. 15 and the bands for joints in 61S-T6, in A54S-H34 and in 3S-F

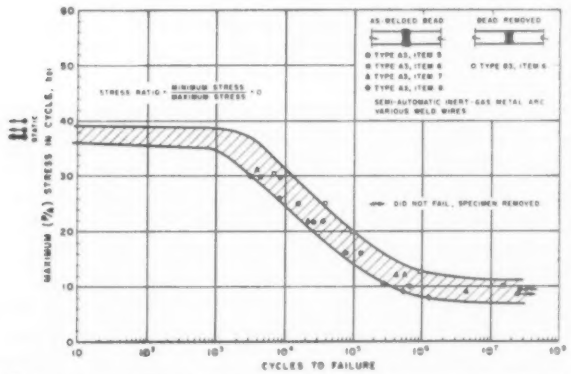

AS-WELDED BEAD
BEAD REMOVED
STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
SEMI-AUTOMATIC INERT-GAS METAL ARC
VARIOUS WELD WIRES
DID NOT FAIL, SPECIMEN REMOVED
MAXIMUM (P/A) STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 11 Results of direct-stress fatigue tests on arc-welded 3/8-in. thick A54S-H34 aluminum alloy plate

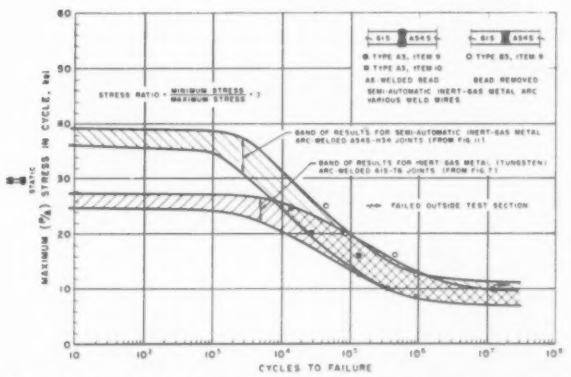

61S
A54S
AS-WELDED BEAD
BEAD REMOVED
SEMI-AUTOMATIC INERT-GAS METAL ARC
VARIOUS WELD WIRES
STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
BAND OF RESULTS FOR SEMI-AUTOMATIC INERT-GAS METAL ARC WELDED A54S-H34 JOINTS (FROM FIG. 11)
BAND OF RESULTS FOR INERT GAS METAL (TUNGSTEN) ARC WELDED 61S-T6 JOINTS (FROM FIG. 7)
FAILED OUTSIDE TEST SECTION
MAXIMUM (P/A) STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 12 Results of direct-stress fatigue tests on arc-welded 3/8-in. thick aluminum alloy plates (A54S-H34 joined to 61S-T6)

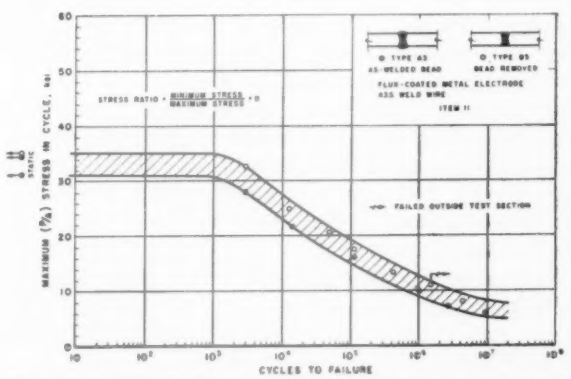


Fig. 13 Results of direct-stress fatigue tests on arc-welded 3/8-in. thick Alclad 14S-T6 aluminum alloy plate

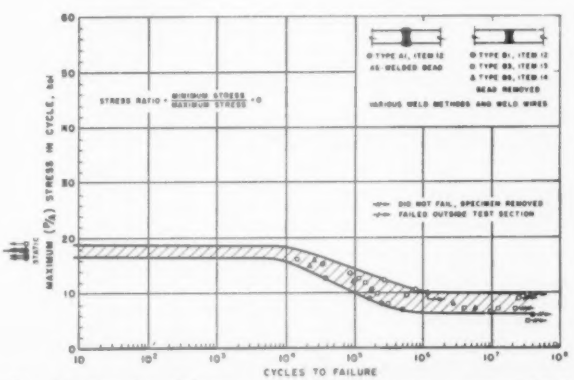

AS-WELDED BEAD
BEAD REMOVED
VARIOUS WELD METHODS AND WELD WIRES
STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
DID NOT FAIL, SPECIMEN REMOVED
FAILED OUTSIDE TEST SECTION
MAXIMUM (P/A) STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 14 Results of direct-stress fatigue tests on arc-welded 3/8-in. thick 3S-F aluminum alloy plate

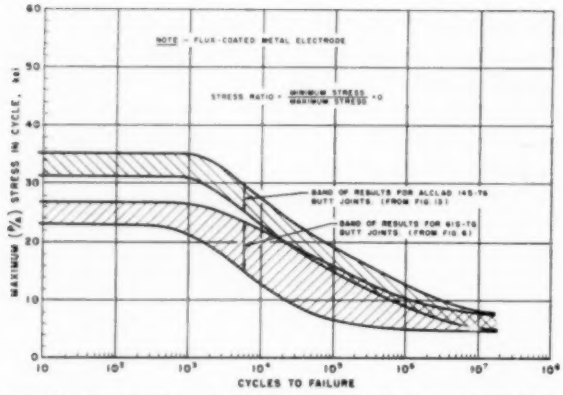

NOTE - FLUX-COATED METAL ELECTRODE
STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
BAND OF RESULTS FOR ALCLAD 14S-T6 BUTT JOINTS (FROM FIG. 13)
BAND OF RESULTS FOR 61S-T6 BUTT JOINTS (FROM FIG. 6)
MAXIMUM (P/A) STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 15 Comparison of direct-stress fatigue test results for arc-welded 3/8-in. thick aluminum alloy plate

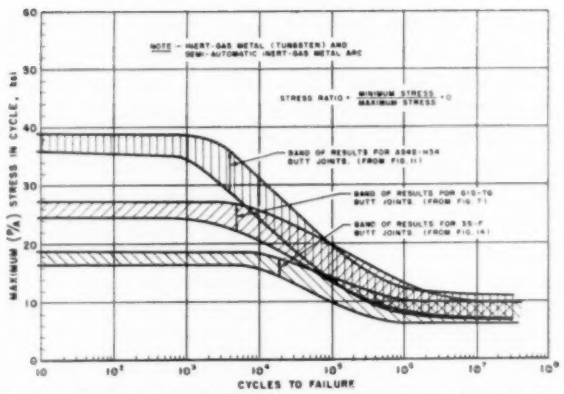

NOTE - INERT-GAS METAL (TUNGSTEN) AND SEMI-AUTOMATIC INERT-GAS METAL ARC
STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
BAND OF RESULTS FOR A548-H34 BUTT JOINTS (FROM FIG. 11)
BAND OF RESULTS FOR 61S-T6 BUTT JOINTS (FROM FIG. 7)
BAND OF RESULTS FOR 3S-F BUTT JOINTS (FROM FIG. 4)
MAXIMUM (P/A) STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 16 Comparison of direct-stress fatigue test results for arc-welded 3/8-in. thick aluminum alloy plate

plates welded by the other processes are compared in Fig. 16. It should be noted that there is very little difference in the positions of the bands at 10^6 cycles. On the other hand, for static tests the bands cover a rather wide range. Table 5 gives a summary of these data comparing the strengths of joints in Alclad 14S-T6 and 61S-T6 and also comparing the strength of 3S-F, 61S-T6 and A54S-H34. Ratios using the strengths of Alclad 14S-T6 and 61S-T6 as numerators are given for the two sets of comparisons.

Figure 17 shows direct-stress fatigue-test results for Alclad 14S-T6 and 61S-T6 plate with an appurtenance attached by a fillet weld made by the flux-coated metal-electrode process. The bands of results shown are for butt-welded joints in plates of the two alloys and it can be seen that the results for these specimens, in general, fall in the lower portion of the bands of results for the respective alloys and weld methods used. It would seem reasonable to conclude, therefore, that the stress raiser at the edge of the fillet weld and the heat of welding produce conditions similar in effect to those of a plain butt-welded joint.

Figure 18 shows a superposition of fatigue strengths obtained at these Laboratories for riveted double-strap butt joints in 61S-T6 plate upon the band of results for welded butt joints made by the inert-gas metal (tungsten) arc process. The main plates of these riveted joint specimens were machined from 1-in. thick rolled rectangular bar to a thickness of 1/4 in., while the cover plates were 3/16-in. thick rolled sheet. The stresses plotted in Fig. 18 were computed on the basis of the gross section of the main plates, that is, 7 1/2 by 1/4 in. Although the static strength of the riveted joint is greater than the maximum strength developed by the welded joints, the fatigue strengths of the welded joints beyond 10^4 cycles to failure compare favorably

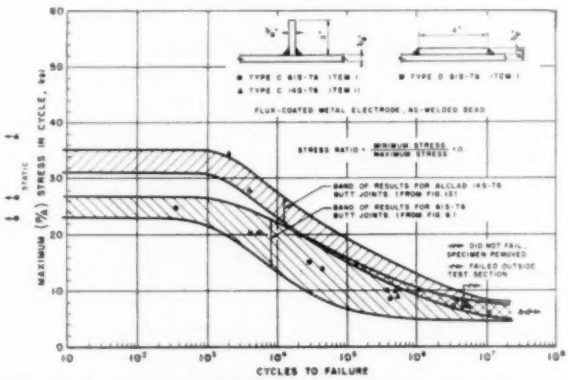

TYPE C 61S-T6 (ITEM 1)
TYPE C 14S-T6 (ITEM 1)
TYPE D 61S-T6 (ITEM 1)
FLUX-COATED METAL ELECTRODE, AS-WELDED BEAD
STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
BAND OF RESULTS FOR ALCLAD 14S-T6 BUTT JOINTS (FROM FIG. 13)
BAND OF RESULTS FOR 61S-T6 BUTT JOINTS (FROM FIG. 6)
DID NOT FAIL, SPECIMEN REMOVED
FAILED OUTSIDE TEST SECTION
STATIC
MAXIMUM (P/A) STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 17 Comparison of direct-stress fatigue test results for arc-welded 3/8-in. thick aluminum alloy plate

Table 5—Range of Band of Results for Direct-Stress Fatigue Strengths of Arc-Welded 3/8-In. Thick Aluminum Alloy Plate

Stress ratio: $\frac{\text{Minimum stress}}{\text{Maximum stress}} = 0$

Limit of range	*Alloy and temper*	*Item No.*	*Fig. No.*	*Maximum (P/A) stress in cycle to failure at:* Static	10^3 cycles	10^4 cycles	10^5 cycles	5×10^5 cycles	10^6 cycles	2×10^6 cycles	10^7 cycles
				Flux-coated metal electrode arc welding							
Upper	61S-T6	1	6	26,700 (1.3)[a]	26,300 (1.3)	22,100 (1.3)	15,900 (1.2)	11,900 (1.2)	10,400 (1.2)	9,300 (1.2)	7,800 (1.1)
	Alclad 14S-T6	11	13	35,300	35,200	27,800	19,300	14,700	12,900	11,000	8,300
Lower	61S-T6	1	6	23,400 (1.4)	21,400 (1.4)	13,000 (1.8)	6,600 (2.3)	5,200 (2.0)	5,000 (1.8)	4,900 (1.6)	4,800 (1.1)
	Alclad 14S-T6	11	13	32,800	30,600	23,200	15,100	10,600	9,000	7,700	5,300
				Inert-gas metal (tungsten) and semiautomatic inert-gas metal-arc welding							
Upper	61S-T6	2,3	7	27,250 [1.5][b]	27,200 [1.4]	25,700 [1.2]	19,700 [1.0]	15,000 [1.0]	13,300 [1.0]	11,900 [1.0]	9,900 [1.1]
	A54S-H34	5–8	11	40,010	38,800	31,400	20,000	14,300	13,000	12,200	11,300
	3S-F	12–14	14	18,410 [2.2]	18,800 [2.1]	18,500 [1.7]	14,600 [1.4]	11,400 [1.3]	10,200 [1.3]	10,000 [1.2]	9,900 [1.1]
Lower	61S-T6	2,3	7	24,600 [1.5]	24,300 [1.4]	20,300 [1.2]	13,500 [1.1]	9,300 [1.0]	8,300 [1.0]	7,800 [1.0]	7,200 [1.0]
	A54S-H34	5–8	11	37,200	34,700	24,700	14,200	9,200	8,200	7,700	7,100
	3S-F	12–14	14	16,590 [2.2]	16,500 [2.1]	15,900 [1.6]	10,000 [1.4]	7,100 [1.3]	6,500 [1.3]	6,400 [1.2]	6,400 [1.1]

[a] Number in parentheses is ratio of strength of Alclad 14S-T6 welded joint to that of 61S-T6 welded joint.
[b] Number in brackets is ratio of strength of A54S-H34 welded joint to that of other alloy-welded joint.

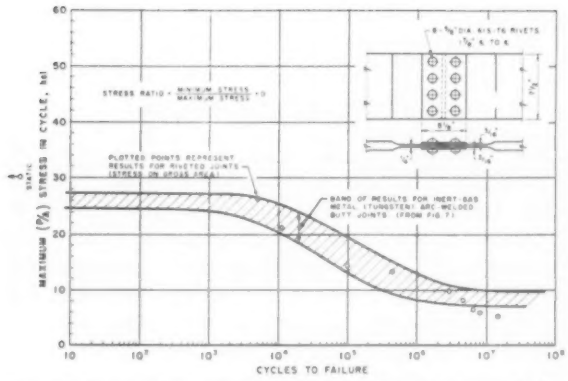

STRESS RATIO = MINIMUM STRESS / MAXIMUM STRESS = 0
PLOTTED POINTS REPRESENT RESULTS FOR RIVETED JOINTS (STRESS ON GROSS AREA)
BAND OF RESULTS FOR INERT-GAS METAL (TUNGSTEN) ARC WELDED BUTT JOINTS (FROM FIG 7)
MAXIMUM (P/A) STRESS IN CYCLE, ksi
CYCLES TO FAILURE

Fig. 18 Comparison of direct-stress fatigue test results for arc-welded and riveted butt joints in 61S-T6 aluminum alloy

with the results for the riveted double-strap butt joints; in fact, the results for the welded joints at 10^7 cycles to failure exceed those for the riveted butt joints. All failures in the riveted joints involved the main plates and occurred through the rivet holes. Fatigue test results, beyond 10^4 cycles to failure, for similar riveted joints in 14S-T6 plate fall within the band of results for welded Alclad 14S-T6 joints made by the flux-coated metal electrode process.

In general, the fatigue specimens with the weld bead left in the as-welded condition failed at the edge of the bead; however, a few specimens with very smooth weld beads failed in the heat-affected zone. The majority of the fatigue failures in specimens in which the weld bead was removed occurred in the heat-affected zone with about 20% of the failures occurring through the weld. Typical fatigue failures are illustrated in Fig. 19. In these typical cases, the cracks are short; however, in some tests, at high stress (low numbers of cycles) the fracture was completed during the period while the machine was stopping after the limit switch shut off the power. Approximately 100 cycles of loading were applied during this period. The effect of spatter marks and transverse scratches in determining the location of the fatigue cracks has been shown in References 1 and 2. A few additional failures of this type have been obtained, but in each case the fatigue strength developed in the specimen was not significantly lower than that of specimens which developed typical cracks.

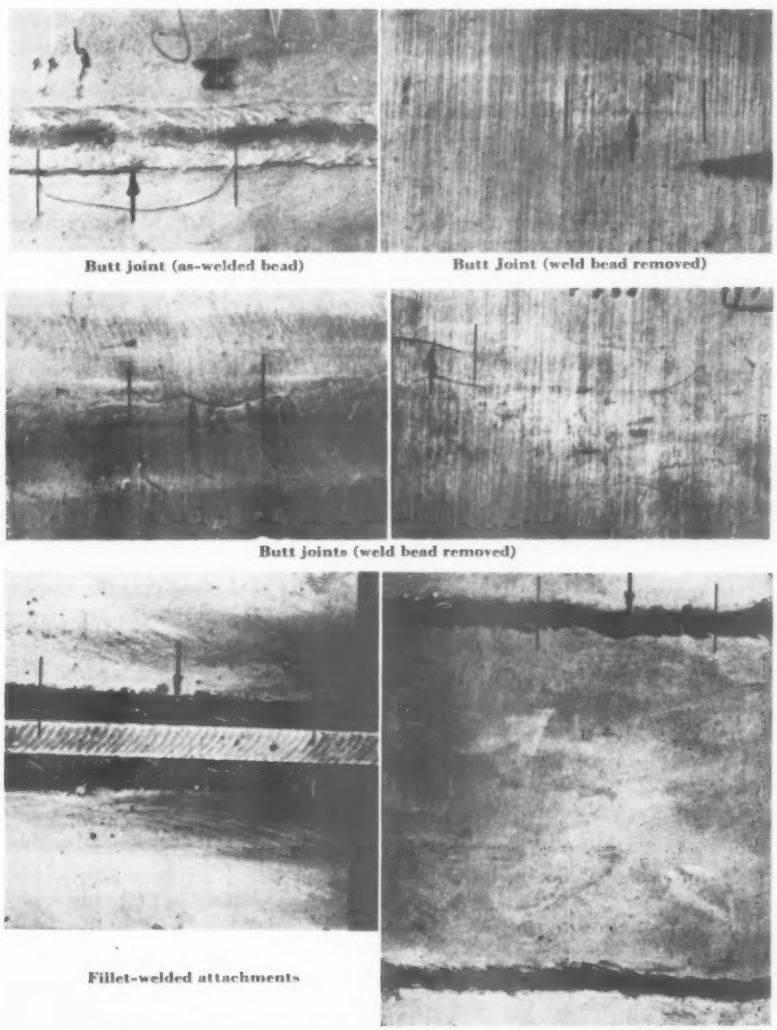


Fig. 19 Location of typical fatigue failures in welded specimens

CONCLUSION

From the foregoing results and discussion of direct-stress fatigue tests of welded specimens of $^3/_8$-in. thick aluminum alloy plates and comparison with riveted butt joints, the following general statements seem warranted:

1. The mechanical properties of the aluminum alloy plates used in the work reported herein meet applicable specified minimum values and compare favorably with published typical values.

2. The welded butt joints fall in the following order of decreasing static strengths: (1) A54S-H34, (2) Alclad 14S-T6, (3) 61S-T6 and (4) 3S-F. The joint efficiencies of the heat-treated alloys are significantly lower than the joint efficiencies of the nonheat-treated alloys.

3. Welding methods that give smooth weld beads provide joints with higher fatigue strengths than methods that produce rough weld beads.

4. The increase in fatigue strength produced by dressing the weld beads flush with the parent

metal depends partially, at least, on the roughness of the as-welded bead but in no case would it be expected that such dressing would have a detrimental effect on the fatigue strength of the weldment.

5. When 61S-T6 plate is arc welded to A54S-H34 plate, the static strength developed by the butt joint is considerably lower than that developed by a joint made by welding A54S-H34 to itself but, for fatigue lives greater than 5×10^4 cycles, the strengths developed are equal to those developed by all-A54S-H34 joints. It should be noted that within this range of fatigue lives the bands of results for welded joints in these two materials practically coincide.

6. The welded butt joints developed fatigue strengths of about the same magnitude as their static strengths for at least 10^3 cycles to failure and in one case, 3S alloy, up to 10^4 cycles to failure.

7. Only slight differences were found in the bands of fatigue strengths of butt-welded joints of the various alloys beyond 10^6 cycles to failure.

8. When an attachment is made to a solid plate by fillet welds, the fatigue strengths are practically the same as those of plain butt-welded joints.

9. For lives between about 5×10^3 and 5×10^6 cycles, the fatigue strengths of plain butt-welded joints and riveted double-strap butt joints agree very well. In the case of 61S-T6, the fatigue strengths of plain butt-welded joints seem to exceed those of the riveted joints at 10^7 cycles to failure.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of G. O. Hoglund and others in the Alcoa Process Development Laboratories in the preparation and welding of the panels. They also wish to acknowledge the contributions of R. L. Templin, Assistant Director of Research and Chief Engineer of Tests, and others at the Aluminum Research Laboratories during the planning and execution of this investigation.

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Initiation and Propagation of Brittle Fracture in Structural Steels

Discussion by G. M. Boyd

With reference to the discussion by Bernhard Persson (THIS JOURNAL, 32 (6), 301-s to 305-s (1953)) the difference of opinion seems to center around the energy value in the Charpy V-notch test required to prevent the catastrophic spread of cracks. The point of view of the authors of the paper is that the "safe" energy level varies according to the steel, while the contention of Mr. Persson is that there is some absolute level, determinable from the ship casualties studied by the National Bureau of Standards.

From a detached viewpoint the position seems to be as follows: The NBS studies showed that for the cases considered there was a certain Charpy V-notch energy level, say 20 ft-lb, above which active cracks did not progress. Referring to the tables of chemical compositions in the NBS reports, however, it can be seen that the very great majority of the steels studied were in the "rimmed," or at most "semikilled" categories.

The paper under discussion, as can be seen by replotting Figs. 7–10 superimposed on the same scale, shows that in order to arrest fractures, under the conditions of the explosion test, higher energy levels are required for the fully killed steels than for the rimmed steels. The observation, which is probably one of the most important revelations of the paper under consideration, does not invalidate the NBS conclusions, but it strongly suggests that their validity should be restricted to the types of steels considered in the NBS studies.

In fact, it may be said that the observation alluded to seriously shakes the widely held belief that the energy level given by the Charpy V-notch test, taken by itself, is a reliable index to the service behavior of all types of steels in regard to their liability to brittle fracture. On the other hand it supports the view that some criterion based upon the character of the fracture, under conditions simulating those of service, would be more reliable.

Whether the Pellini explosion test does or does not truly simulate service conditions is of course a debatable question, and the answer clearly depends on the type of service one has in mind. This test is probably more severe than some of the "static" tests such as the Navy tear test and the Tipper notch tensile test, but there is every reason to believe that the same trend, expressed by the observation alluded to above, would also be shown by such "static" tests.

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Paper by Peter P. Puzak, Earl W. Eschbacher and William S. Pellini was published in the Supplement to the December 1952 issue of THE WELDING JOURNAL, pp. 561-s to 581-s.

The Plastic Fatigue Strength of Pressure Vessel Steels

Comparison of plastic fatigue properties of a high-strength steel and a carbon-pressure-vessel steel including strain behavior, surface preparation, testing temperature, welding and heat treatments

by J. H. Gross, D. E. Gucer, R. D. Stout

FORWORD

THE investigation reported in this paper was sponsored and guided by the Fabrication Division of the Pressure Vessel Research Committee. P. R. Cassidy is Chairman and B. E. Rossi is Executive Secretary of the Pressure Vessel Research Committee. F. L. Plummer is Chairman of the Fabrication Division, while the project Steering Committee is composed of I. E. Boberg, L. C. Bibber, W. P. Gerhart and A. R. Lytle.

INTRODUCTION

In previous papers[1, 2] a testing method was described for evaluating the resistance of steels to repeated loads in the plastic range. The effects of fabrication operations, such as cold working, welding and heat treatment, were reported for several pressure vessel steels. Loading was conducted in the plastic range in order to produce failure in a range of cycles significant to pressure vessel operation, and to study the possible relation of such loading to pressure vessel failures.

The present investigation was directed toward a comparison of plastic fatigue properties of a high-strength Mn-Mo steel, ASTM A-302, Grade B, and a carbon-pressure-vessel steel, ASTM A-201. If higher strength steels are applied to vessels designed for increased stress levels, assurance is needed that the other mechanical properties of these steels will meet the requirements of service. In addition, this program was to parallel tests at the University of Illinois on larger hydraulic-loaded plate specimens and tests on model vessels at the École Polytechnique, all on the same heats of A-302 and A-201 steels.

J. H. Gross, D. E. Gucer and R. D. Stout are with Lehigh University Bethlehem, Pa.

Presented at the AWS Thirty-Fourth National Fall Meeting held in Cleveland, Ohio, week of Oct. 19–23, 1953.

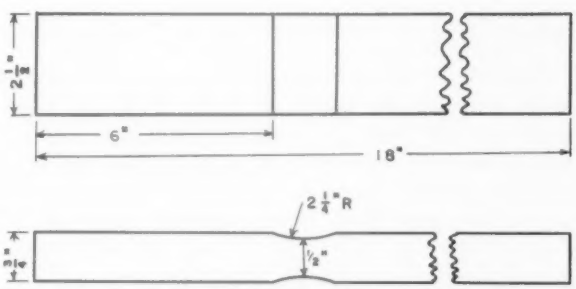

Fig. 1 Biaxial plastic fatigue specimen

The following phases of the program were investigated:

1. Strain behavior in the specimen during cycling.
2. Effect of surface preparation.
3. Effect of temperature during testing.
4. Effect of welding and stress relieving.
5. Tests under constant maximum loading instead of constant deflection.
6. Influence of heat treatment and microstructure.

These will be described and discussed in order.

TESTING METHODS AND MATERIAL

Tests at Constant Deflection

The details of the testing method have been presented previously.[2] The specimen, shown in Fig. 1, was loaded as a cantilever beam in the machine shown in Fig. 2. This machine is a cam-type loading device providing essentially constant deflection amplitude during testing. The specimen was sufficiently wide to set up 2:1 biaxial strains.

Tests at Constant Maximum Load

The investigations at the other cooperating laboratories utilize oil pressure pulses for cycling which constitute loading to a constant maximum pressure as opposed to the constant deflection characteristics of the

machine of Fig. 2. In order to determine whether the behavior of the steel under constant deflection is essentially the same or significantly different as compared to constant loading, a second machine was constructed, as shown in Fig. 3. This machine is operated with compressed air, which furnishes loading by means of the opposing cylinders. The air pressure is controlled in a secondary tank, fed from the main tank, to plus or minus 0.5 lb at levels varying from 50 to 100 lb. The cycling is carried out at 100 cpm by means of a synchronous motor operating a microswitch and in turn alternately activating three-way solenoid air valves. The loading is approximately square-wave in nature. When the specimen has cracked to an extent which allows the deflection to become $^1/_2$ in., limit switches stop the test. The results of tests carried out on this machine are presented in a later section.

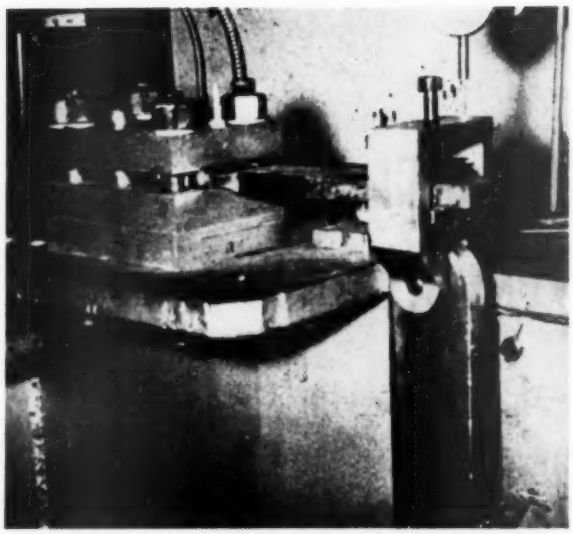

Fig. 2 Constant deflection fatigue machine

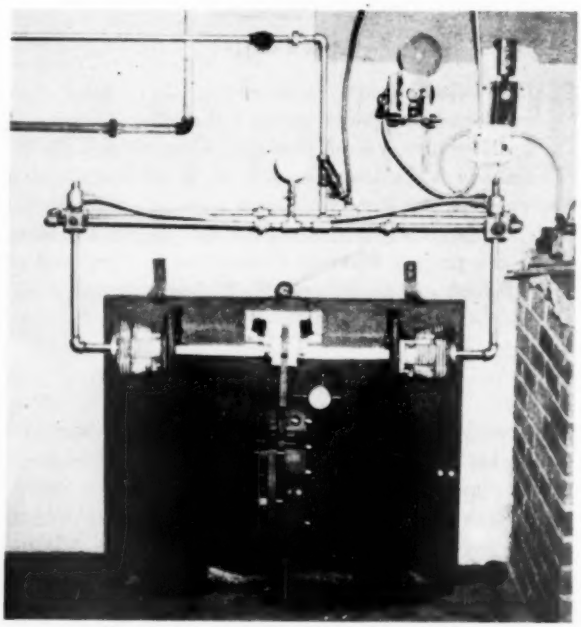

Fig. 3 Constant load fatigue machine

Steels

The steels used for testing consisted of two heats each of A-302 and A-201 in $^3/_4$ in. thickness. The analyses and tensile properties of these heats in the normalized and stress-relieved condition are given in Table 1. The "standard" heats are those under test at Illinois and École Polytechnique, available in limited quantity. The "new" heats represent additional material needed for further tests.

Strain Behavior in the Specimen

One of the problems involved in fatigue testing in the plastic range is to express the severity of loading in quantitative and significant terms. The stress values used in elastic loading lose validity, while strain values possess certain ambiquities which are demonstrated later on.

In previous investigations, as a first approximation, the strain imposed on the initial tension cycle was used as an index of the loading range. It appeared desirable to study the strain produced throughout the test life of the specimen to permit the best choice of a criterion for indicating the severity of plastic loading. A second

Table 1—Tensile Properties of PVRC Steels

(Normalized at 1650° F, stress relieved at 1150° F; 0.05 in. diam, 2-in. gage length)

	Yield strength, 0.2% offset	*Ultimate tensile strength, psi*	*Reduction of area*	*Elongation, 2 in.*
Standard A-201	37,300	59,000	67.7	40.0
	35,400	59,000	69.3	39.0
New A-201	35,900	57,000	70.3	39.0
	37,100	58,500	68.9	39.0
Standard A-302	64,600	87,200	65.1	27.0
	67,000	86,900	63.3	25.5
New A-302	59,500	79,500	66.7	28.0
	57,200	77,600	66.3	30.5

	Chemical analyses of PVRC steels, %					
	C	*Mn*	*P*	*S*	*Si*	*Mo*
Standard A-201	0.14	0.38	0.017	0.034	0.20	...
New A-201	0.13	0.39	0.013	0.030	0.20	...
Standard A-302	0.16	1.44	0.026	0.032	0.27	0.43
New A-302	0.15	1.17	0.019	0.023	0.27	0.41

reason for such a study arose from the fact that specimens of unlike strength experience different strains at identical deflections. In general, greater strength results in lower strain in the test section.

Strains in the test section were measured with a Tuckerman optical gage. The gage length was $^1/_4$ in. centered at the minimum cross section. Strains were measured at small increments of deflection during the first tension cycle and then were recorded from maximum tension to maximum compression at frequent

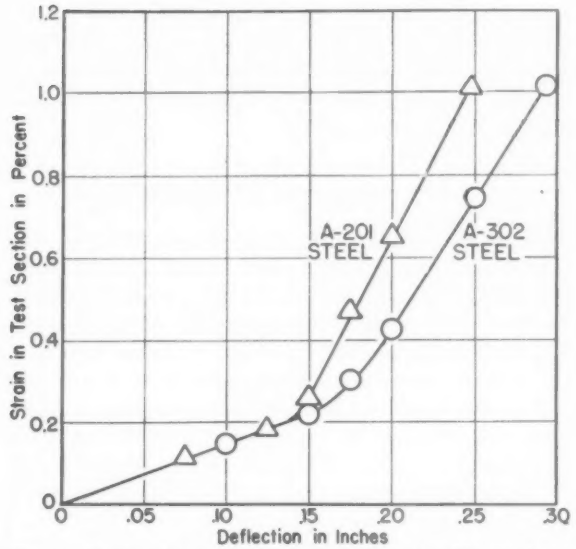

Fig. 4 Strain characteristics of A-302 and A-201 steels on first tension cycle

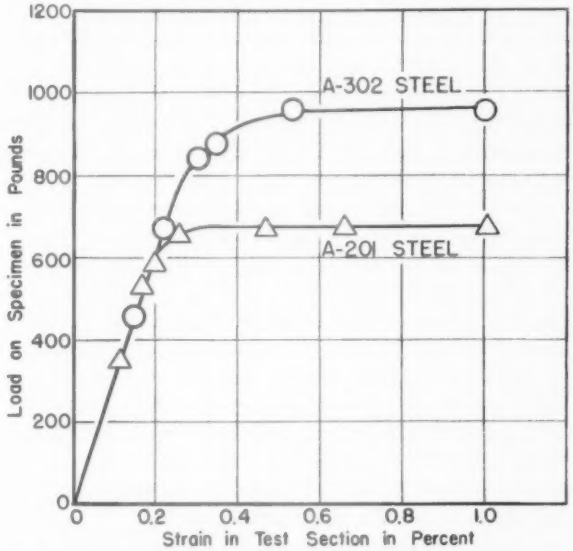

Fig. 5 Load-strain characteristics of A-302 and A-201 steels on first tension cycle

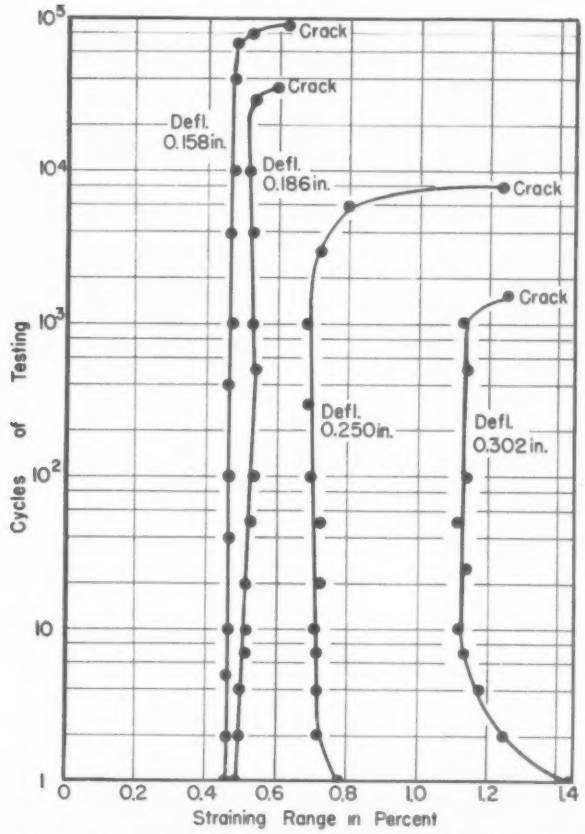

Fig. 6 Effect of cycling on straining range produced in A-302 steel under constant deflection

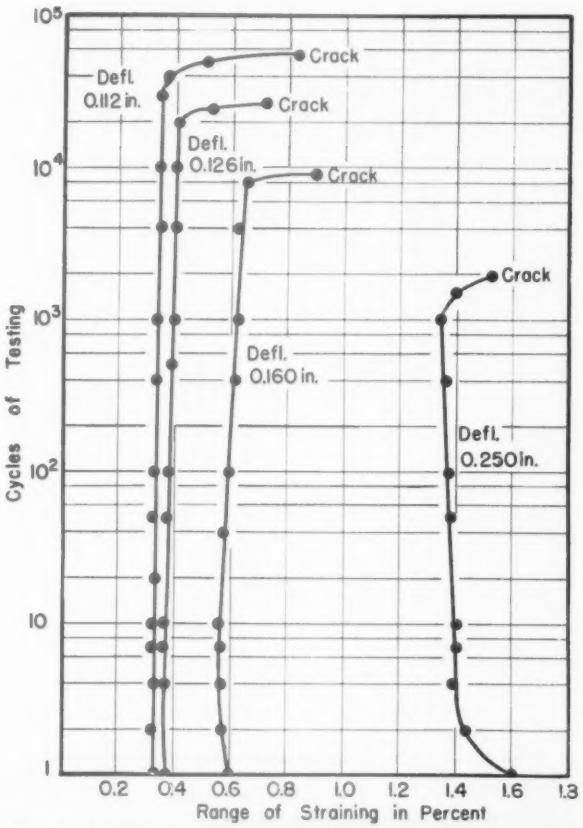

Fig. 7 Effect of cycling on straining range produced in A-201 steel under constant deflection

intervals until the specimen developed a crack. Loads were also recorded on several of the tests by means of strain gages affixed to the loading arm of the machine.

The relation between deflection, strain and loads for the normalized and stress-relieved A-302 and A-201 on the first tension cycle is shown in Figs. 4 and 5. In the elastic range, the two steels behave nearly identically. Because of its lower yield strength, the A-201 commences large plastic strain at lesser deflections than the A-302. Thereafter, a given deflection induces greater plastic straining in the test section of the A-201 steel than in that of A-302. The loads required to deflect the specimen likewise differ between the steels, as to be expected from unequal tensile strengths.

Under cyclic loading in the plastic range, the resistance of the steel to failure can be expected to depend on the range of strain imposed throughout the test. The variation of strain with cycling is shown for the standard heats of two steels in Figs. 6 and 7. The strain is expressed as that produced between the points of maximum tension and maximum compression. At high deflections, the strain range decreases noticeably during the first few cycles because of work hardening. After about 10 cycles, there is little change in the strain. At low deflection levels, the strain is nearly constant during the test. The sudden increase in strain toward the end of the test indicates the initiation of a crack in the gage section.

It should be possible according to these data, to express the severity of loading fairly by the average straining range effective during testing. Representative values will be obtained by choosing the readings at 10 or 100 cycles. The relation of straining to deflection at 10 cycles for the two steels is indicated in Fig. 8. At low deflections the two steels behave about alike, but at large deflections the A-201 is strained considerably more than A-302, much as was shown in Fig. 4 for the initial tension cycle. The straining range after 10 cycles was chosen as the criterion to express the degree of loading. It should be noted however, that the conclusions reached in this paper would not be significantly altered if some other number of cycles were substituted, including the initial tension cycle. In Fig. 9, strain ranges at 10 cycles are shown for the new heats of A-302 and A-201.

EFFECT OF SURFACE PREPARATION

The influence of the surface charcteristics on the fatigue endurance limit is well known. Cracks, discontinuities, tool marks and similar surface irregularities lower the fatigue life seriously. Two questions therefore required consideration: (1) Is the action of the surface as strong in plastic fatigue as it is in the elastic range? and (2) What relative sensitivity is shown by a high strength steel and a carbon steel to surface conditions? A series of surface preparations, selected to furnish information on these points, included the following:

1. Polished to a 3/0 finish by hand.
2. Machined by a milling cutter.
3. Scaled (by normalizing treatment).
4. Scaled and pickled.
5. Notched 0.01 in. deep with a cutter $2^1/_2$ in. in diam, 45 deg included angle and 0.01 in. tooth radius.

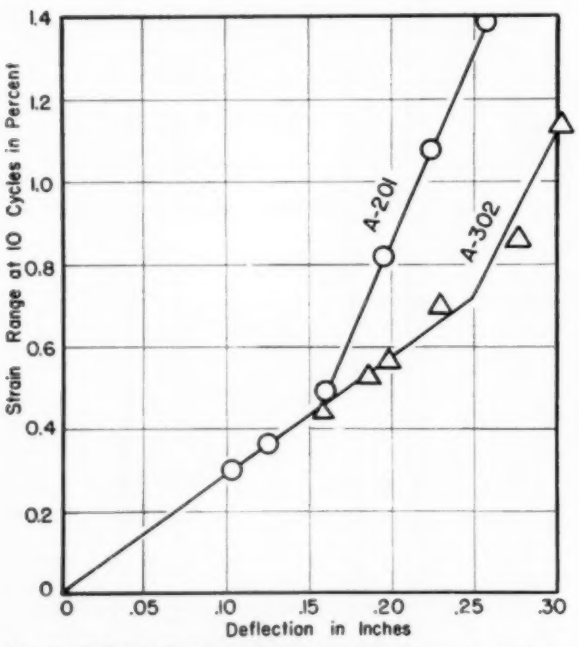

Fig. 8 Relation between deflection and the range of straining at 10 cycles for the standard heats of A-302 and A-201 steels

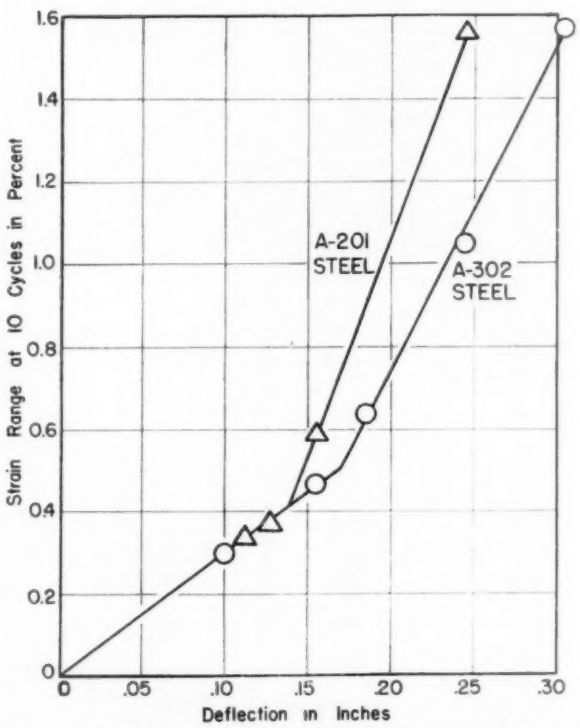

Fig. 9 Relation between deflection and the range of straining at 10 cycles for the new heats of A-302 and A-201 steels

6. Punch-marked by a Rockwell diamond indenter to a depth of 0.017 in. at $^1/_2$ in. intervals across the test specimen.

All specimens except the polished series were stress relieved as the final operation before testing. The notch for condition 5 above was produced by lowering the milling cutter, without lateral movement, the required depth into the center of the test section. The resulting notch was about $^3/_8$ in. long and was perpendicular to the axis of the specimen. Specimens for each condition were tested at four strain levels with triplicates at each level. The number of cycles to initiate the first visible crack was observed and also the number to cause failure of the specimen as indicated by loss of load carrying capacity.

The results of these tests are shown in Figs. 10 and 11. The most favorable surface should be the polished one.

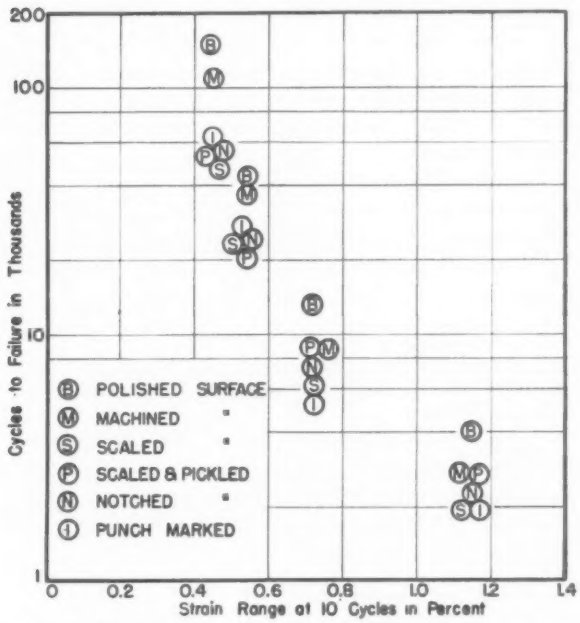

Fig. 10 Effect of surface preparation on the plastic fatigue resistance of A-302 steel

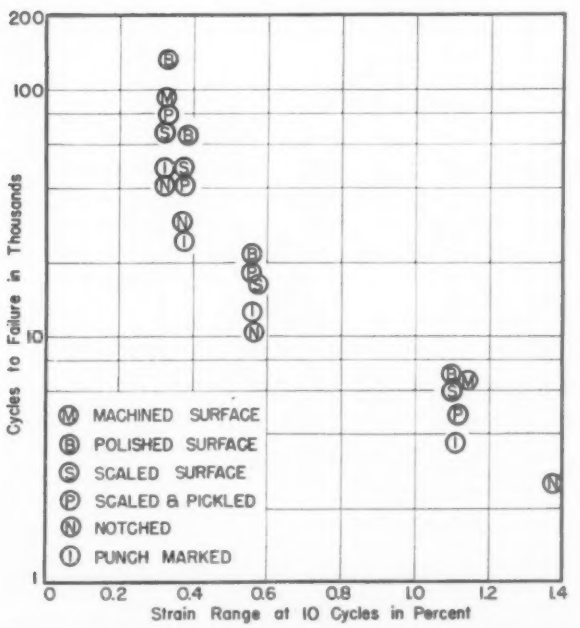

Fig. 11 Effect of surface preparation on the plastic fatigue resistance of A-201 steel

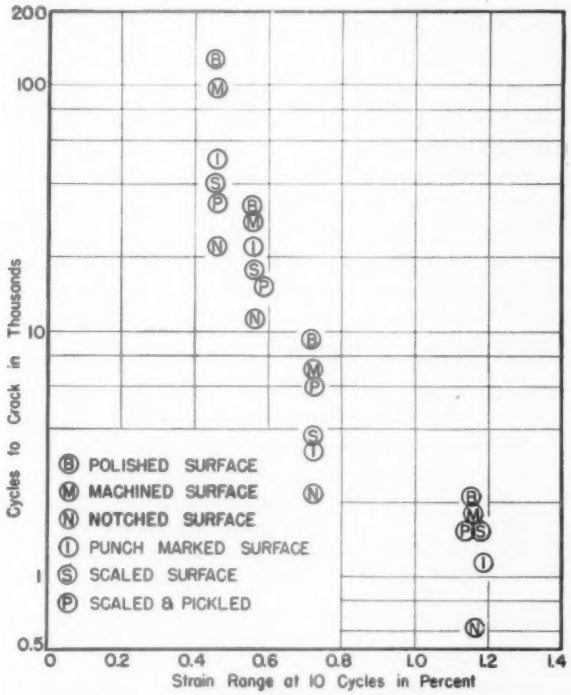

Fig. 12 Effect of surface preparation on the incidence of initial cracking of A-302 steel in plastic fatigue

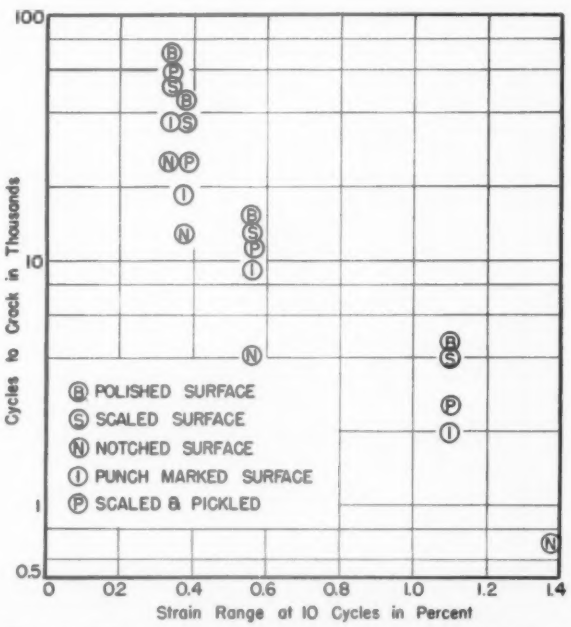

Fig. 13 Effect of surface preparation on the incidence of initial cracking of A-201 steel in plastic fatigue

The points for this condition lie at the top of the groups of data, that is, they show the largest cycles to failure. For the A-302 steel in Fig. 10 the other conditions are fairly closely grouped at levels 30–40% lower than the polished series. The results for the A-201 are more scattered. The effects of scaling or pickling seem small, but the notches and punchmarks about halved the fatigue life.

A similar plot is shown in Figs. 12 and 13 for the effect of surface preparation on the cycles to the first crack. The noticeable difference between these results and those of Figs. 10 and 11 is that notches or punchmarks are highly effective in lowering the cycles to the first crack. This behavior is to be expected since cracking originates early in the vicinity of these stress raisers. The life of the specimen after cracking is little affected by the surface preparation. Notice in the following table that the cycles between initial cracking and failure were much the same for polished and notched specimens at all straining levels. Some of the scatter is due to the lower precision with which the cycles for cracking were determined:

Cycles Between Cracking and Failure

	—*A-201 steel*—		—*A-302 steel*—	
Strain level	*Polished*	*Notched*	*Polished*	*Notched*
(1) Lowest	40,000	18,000	20,000	30,000
(2)	20,000	16,000	10,000	14,000
(3)	6,000	7,000	4,000	5,000
(4) Highest	2,500	1,800	2,000	1,600

Generally, one can conclude that the two steels respond in about the same way to surface variations. The high-strength steel does not show a greater sensitivity to surface irregularities than the carbon steel. The influence of these variations in plastic fatigue is similar to that observed in elastic fatigue tests, except that it may be somewhat less marked in the plastic range.

TESTS AT LOW TEMPERATURE

A cold chamber was installed on the fatigue machine for tests at low temperature. By means of dry ice, the test section could be held at about 0°F as compared to the 90–125° F temperature present in the section when it was tested in the open. Tests were run on both heats of A-302 steel in the normalized and stress-relieved condition.

The test data are shown in Fig. 14. It will be seen that the results were essentially alike for 0° F and room temperature. This is to be expected since the strength of the steel changes very little in the temperature range covered.

EFFECT OF WELDING AND STRESS-RELIEVING

Specimens were prepared with longitudinal bead-weld deposited in accordance with the conditions prescribed in the correlation chart relating the projects at the three cooperating Universities. These welding conditions were as follows:

A-201 steel 1/4 in. E7016	300 amp, 12 ipm
A-302 steel 1/4 in. E8015Q	300 amp, 12 ipm, 350° F preheat
1/4 in. E12015	300 amp, 12 ipm, 350° F preheat

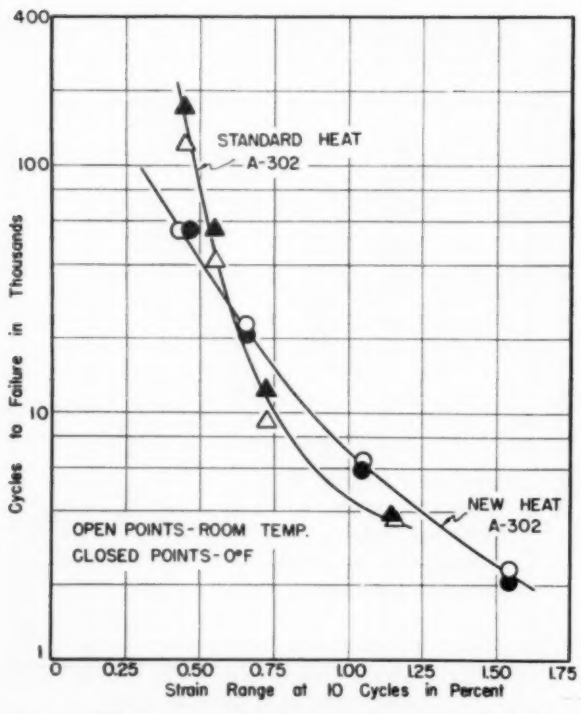

Fig. 14 Effect of low temperature on the plastic fatigue resistance of A-302 steels

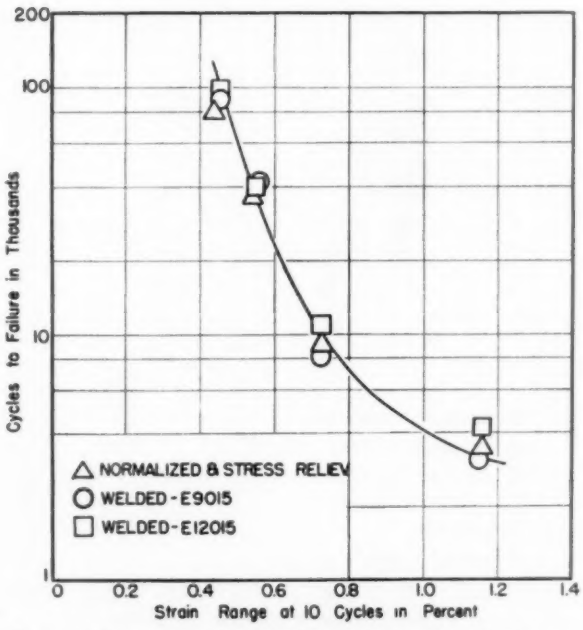

Fig. 15 Effect of welding followed by stress relieving on plastic fatigue resistance of standard A-302 steel

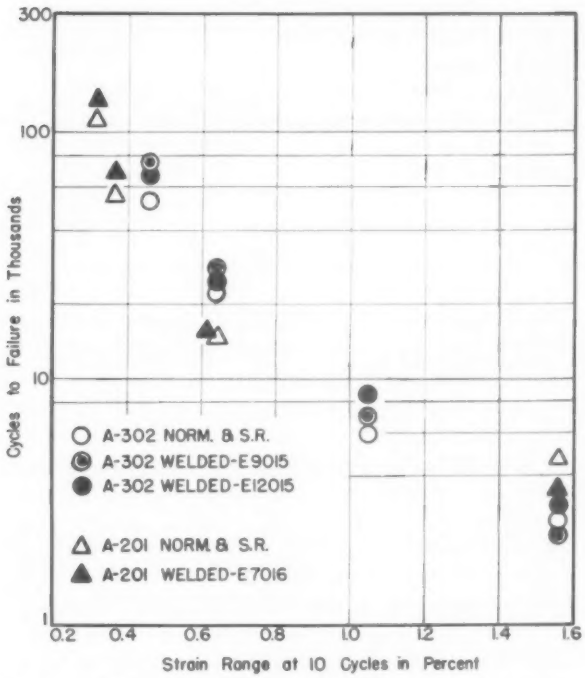

Fig. 16 Effect of welding followed by stress relieving on plastic fatigue resistance of new heats of A-302 and A-201 steels

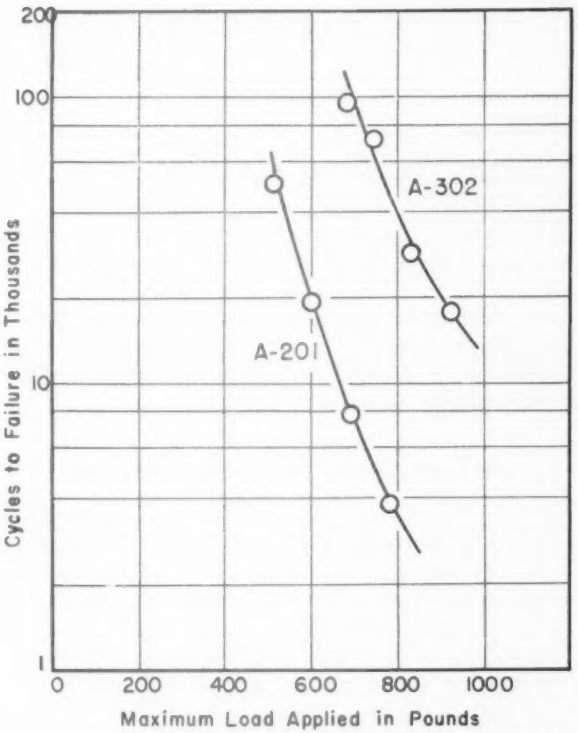

Fig. 17 Comparison of plastic fatigue resistance of A-302 and A-201 steels under constant load tests

Both heats of A-302 and the new heat of A-201 were tested. All specimens were normalized before welding and were grooved and stress relieved at 1150° F afterward.

As shown in Figs. 15 and 16, welding raised the cycles to failure slightly at low testing strains. At high strain levels, the welded specimens tended to fall in performance slightly below the unwelded ones. The initial cracking showed an inclination to avoid the weld metal at low strains, but at high strains the weld metal generally initiated cracking. The specimens welded with E12015 were consistently better at high-strain levels than those welded with E8015.

In general, the changes introduced by the welding operations were minor. When, as in these tests, the geometrical effects of weld ripples, undercut and the like are removed by machining, the effects of welding followed by postheating appear small in these structural steels.

TESTS AT CONSTANT MAXIMUM LOADS

The new heats of A-201 and A-302 steels were tested in the constant-loading machine. The effect of the loading level on the cycles to failure for the two steels is shown in Fig. 17. The A-302 shows a much higher plastic fatigue strength than the A-201.

By the use of dial gages, each loading level in the pneumatic machine could be connected with the amount of deflection of the specimen. The results obtained on the pneumatic machine could then be compared at equal deflections to those obtained on the cam machine. As indicated by Fig. 18, the two types of testing show good agreement.

An attempt was made to produce failure in a specimen by loading it from one direction only. This method was intended to reproduce the type of loading in the Illinois specimen. At a pressure sufficient to bend the specimen initially to a high deflection, no fail-

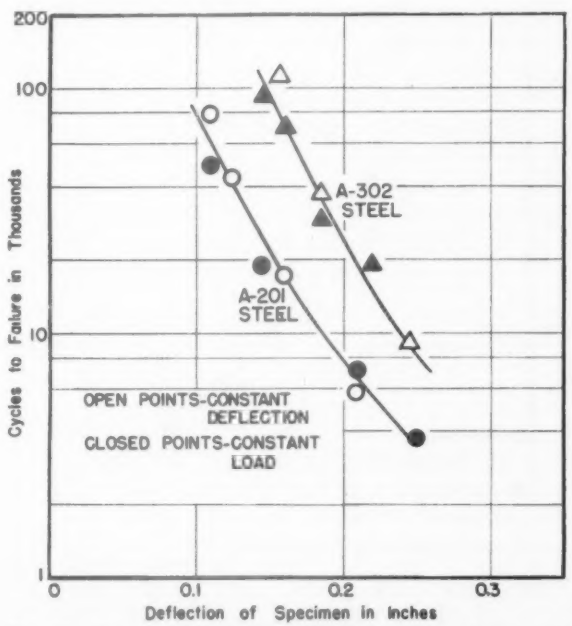

Fig. 18 Comparison of constant deflection and constant load tests on new A-302 and A-201 steels

Table 2—Tensile Properties of New A-302 Steel Treated in Various Ways

(0.505 inch diam., 2 inch gauge length)

Treatment	*Yield strength, psi, 0.2% offset*	*Tensile strength, psi*	*Elongation, %*	*Reduction area, %*	*Max. strain, % at 10th cycle in fatigue spec.*	*Max. load, lb. at 10th cycle in fatigue spec.*
Annealed, 1650° F	50,000	73,000	31.8	61.5	1.62	995
Norm. 1650° F, S.R. 1150° F	58,000	78,500	29.2	66.5	1.57	1040
Prestrained 10%	90,000 (?)	90,000	17.5	63	1.22	1080
W.Q. 1650° F, temper 400° F	160,000	196,000	14	52	1.25	1800
W.Q. 1650° F, temper 1300° F	74,000	92,500	27.5	72	1.22	1100

ure was obtained after several hundred-thousand cycles. This result suggest that the Illinois plate specimen loaded as a diaphragm contains enough constraint to induce complex straining at its center.

INFLUENCE OF HEAT TREATMENT

It is not at all clear what influence the metallurgical structure of the steel as influenced by heat treatment or cold work may have on fatigue resistance particularly in the plastic range of loading. Some early results of an investigation of this subject can be included here.

Metallurgical variations were introduced into the new heat of A-302 steel by subjecting fatigue specimens to the following preliminary treatments:

1. Annealing at 1650° F.
2. Normalize at 1650° F., stress relieve at 1150° F.
3. Normalize at 1650° F., prestrain 10% in tension.
4. Water quench from 1650° F., temper at 400° F, 1 hr.
5. Water quench from 1650° F, temper at 1300° F, 1 hr.
6. Normalize at 2000° F, stress relieve at 1150° F (for coarse grain).

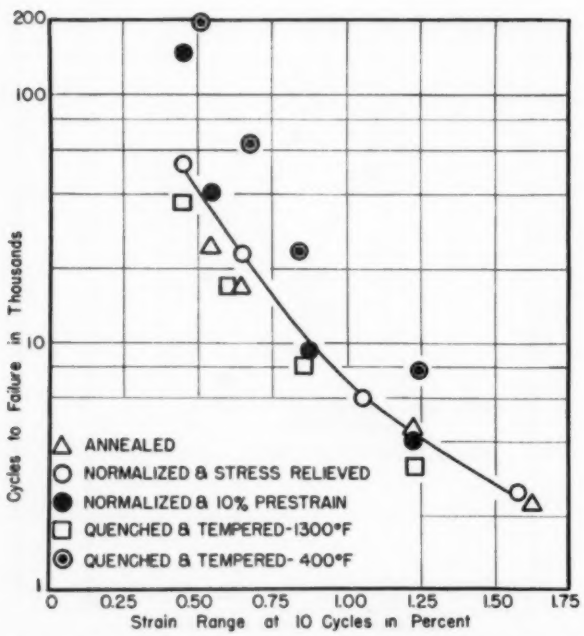

Fig. 19 Effect of heat treatment and cold work on plastic fatigue strength of new A-302 steel

In addition to plastic fatigue tests, tension tests were made on specimens receiving each treatment. The results of testing are given in Table 2. Also shown are the maximum straining range and the load imposed during fatigue testing.

The results of the plastic fatigue tests are summarized in Fig. 19. Annealing, normalizing, cold working and quenching and tempering at 1300° F all produced relatively small variations in fatigue resistance despite the range of microstructure that they represented. The specimens treated to high strength (Treatment 4) showed a great superiority over the others at all straining levels. Again the importance of tensile strength even in fatigue tests involving relatively large plastic flow is demonstrated. Cold work raises the cycles to failure only at the lowest strain level, which is probably within the elastic range for this condition.

The effect of coarse grain was not shown in Fig. 19 to preserve clarity. Normalizing at 2000° F produced a slightly harder structure than at 1650° F but little change in fatigue resistance except at the lowest strain level where the cycles to failure were raised about 20%.

Further tests in this field are planned.

SUMMARY

The results of the investigation reported here can be summarized as follows:

1. When fatigue tests are conducted in the plastic range, the conditions of testing become ambiguous. The amount of straining per cycle is probably the most significant quantity to measure testing severity.

2. In bending fatigue, the amount of strain produced by a given deflection of the specimen will vary with the tensile strength of the steel and therefore must be determined for each analysis and condition of specimen.

3. The range of strain in the specimen changed slightly with cycling. The strain range after 10 cycles of loading appeared to be a representative value at all levels of testing strain. This is the criterion of strain level adopted in the present investigation.

4. Surface irregularities can lower the plastic fatigue resistance markedly. Fabrication operations introducing scaling, pickling, punchmarking or other similar surface disturbances lowered resistance 10 to 50% as compared to a polished surface.

5. Ambient testing temperatures around 0° F did

not alter the fatigue properties observed at room temperature.

6. When welding was followed by postheating, it produced a negligible change in plastic fatigue properties.

7. Heat treatment appeared to affect the fatigue resistance only when it also changed the tensile strength considerably.

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2. Gross, J. H., Tsang, S., and Stout, R. D., "Factors Affecting Resistance of Pressure Vessel Steels to Repeated Overloading," *Ibid.*, 32 (1), Research Suppl., 23-s to 30-s (1953).

Moisture in Low-Hydrogen Welding Electrodes

by C. DeRop and H. Schmidt-Bach

LOW-HYDROGEN electrodes are characterized by a coating that yields a basic slag. The coatings are high in fluorspar and in calcium carbonate, which releases CO_2 by endothermic decomposition. The first suggestion that limestone and fluorspar be used in large quantities in electrode coatings was made in 1921 (British Patent 192,852 issued in 1923). Although their mechanical properties are excellent, low-hydrogen electrodes tend to deposit porous, rough beads. This is due to too rapid freezing of the globular weld metal. Porosity is particularly to be guarded against in vertical joints and in joints with poor fit-up. In both situations low current must be used, which increases the cooling rate.

The composition and properties of two new low-hydrogen electrodes are shown in Table 1. A few fish eyes were observed in the tensile fractures. If the specimens had been allowed to remain at room temperature for three months or had been heated several days at 120° C there would have been no fish eyes. In view of the low-hydrogen content of the weld metal it is difficult to attribute the fish eyes to it. The cause may lie in grain boundary segregations that cause even the smallest traces of hydrogen to be effective. The notch impact value of the weld metal is high even at −70° C.

Abstract of "Die Entwicklung kalkbasisch umhullter unlegierter Schweisselektroden," published in *Stahl und Eisen*, 73, 1212–1215, Sept. 10, 1953. Abstracted by Dr. G. E. Claussen.

at which electrode A developed 7.9 to 9.1 mkg/cm² and electrode B 5.1 to 5.2 mkg/cm². Electrode A is designed for high tensile steels up to 85,000 psi tensile strength. Electrode B is used on the lower tensile plain carbon and low-alloy steels. The pulsating tension fatigue strength of Electrode A in the form of machined specimens from a butt weld in $^7/_8$-in. thick plate was 28,000 ± 25,000 psi at 2 million cycles.

The absorption of moisture by the coatings was measured at 70 and 100% humidity after drying 2 hr at 200° C. At 70% humidity the electrodes had seemed to reach equilibrium at a moisture content close to 1.4% after 84 hr. At 100% humidity the moisture content after 84 hr was 1.7 to 1.9%. Up to 1.4% moisture surface beads show no porosity. Beyond this content porosity usually is observed. Porosity is developed only by the first inch or two of the electrode. So long as the humidity does not exceed 65%, commercial low-hydrogen electrodes can be exposed indefinitely without porosity. In case the humidity is higher the electrodes may be dried 2 hr at 200° C to restore freedom from porosity. There is no relation between the moisture content of the coating and the number of holes observed. Two tests for moisture contents over 1.5% are the difference in color and the appearance of the inner surface of the slag. Dipping the electrode in water before welding may reduce the porosity. The evaporation of water cools the outer layer of the coating and favors the formation of a protective cylinder around the arc.

Table 1—Composition and Properties of Weld Metal Deposited by Two of the Most Recently Developed Low-Hydrogen Electrodes

Electrode	Current	Weld metal composition, % C	Si	Mn	P	S	H_2	N_2	O_2	Electrode	Yield point, psi	Tensile strength, psi	Elongation, % in 5 diam	Reduction of area, %	Notch impact value,* mkg/cm² Not aged	Aged
A	Reverse polarity	0.084	0.94	0.92	0.036	0.031	0.00021	0.0020	0.024	A	70,000	79,500	31.2	59.7	16.3	12.6
A	AC	0.097	0.96	0.98	0.038	0.020	0.00030	0.0024	0.027	A	70,500	80,000	30.7	59.3	15.9	11.3
B	Reverse polarity	0.11	0.72	0.77	0.029	0.027	0.00026	0.0046	0.031	B	61,500	70,000	32	62.7	14.8	8.6
B	AC	0.13	0.67	0.70	0.039	0.024	0.00034	0.0058	0.033	B	62,500	71,000	31.4	60.8	13.2	7.1

* DVM specimen. The aging treatment consisted of cold elongation 10% followed by heating 30 min at 250° C.

An Investigation of Welded Rigid Connections for Portal Frames

Tests of eleven typical knees used in welded single-span steel rigid frames with evaluation of each type and suggestions for improvment

by A. A. Toprac

I. INTRODUCTION

THE term "rigid frame" has usually been applied to designate a type of structure which is composed of vertical and horizontal* members rigidly attached at their intersection, in such a manner that complete continuity exists in the transfer of moments, shears and direct forces. Rigid (or continuous) frames used for buildings and bridges may prove to be more economical than simple span construction, depending on various factors, among which are the cost of fabrication and erection.

In this paper, however, attention is directed to the single-span steel rigid frame often referred to as a "portal frame." The factor which probably contributes most to the use of steel portal frames is their attractive appearance and their adaptability to both riveted and welded fabrication.[1] The successful introduction of welding into the steel construction field has made the fabrication of such frames more economical.

The Head Designer of the Bureau of Yards and Docks, A. Amirikian, speaking on this subject, states: "There has been ample evidence, too, regarding the savings due to the use of welded framings. These economies have been proved by competitive bids, as well as by actual construction costs."[2]

During a meeting in New York of the Structural Steel Committee of the Welding Research Council, A. Amirikian further stated: "To properly exploit the full advantages of welding fully continuous construction must be utilized."

Continuity is dependent upon the manner in which the various members of a structure are connected. Connections are a very important component part of rigid frames. They can be regarded as "traffic circles" for stresses. Their importance resulted in early attention to connections in the project "Welded Continuous Frames and Their Components" which is being carried out at Lehigh University. The results of the Lehigh investigations on welded rigid connections have been reported previously.[3-5]* The tests that are reported below were carried out at the University of Texas, Department of Civil Engineering. These tests will hereafter be named the "Texas program," to distinguish them from similar work carried out at Lehigh, which will be called the "Lehigh program." The test results of 5 knees out of 11 of the Texas program are closely related to the investigations of the Lehigh program.

Since the above-mentioned programs are closely related, it should be of interest to look at two of the results obtained in previous investigations. Figure 1 is a bar chart of the relative cutting and welding times for the connections of the Lehigh program, with the specimens shown at the left of each bar.[3] Figure 2 illustrates the principal types of knees. The bar for Knee A has been given a length of unity and the remaining bars have been given proportionate lengths—the proportion in every case being stated at the end of each bar. Attention is directed to the fabrication time of square knees, which are the top four bars, and also to the subsequent three bars for the bracket-type knees. The square knees are relatively the cheapest, with the bracketed next in line, as compared with the other types.

Figure 3 is a summary of the behavior of the various connections of the Lehigh program when compared with 8B13 rolled section. (Note that most of the square knees were more flexible in the elastic and early plastic range.) On the other hand, the Type 4 connections, D, E and F, proved to be stronger and more rigid. Since from cost of fabrication point of view the square types and the Type 4 bracketed connections are the most economical, their further investigation has been found desirable.

The Type 4 connections when compared with the rolled section are more than 50% stronger and more

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Presented at the National Spring Meeting, Houston, Tex., June 16–19, 1953.

* Horizontal, or at an angle as in gabled roofs.

* Nomenclature and terminology used in this report is the same as in References 3, 4 and 5.

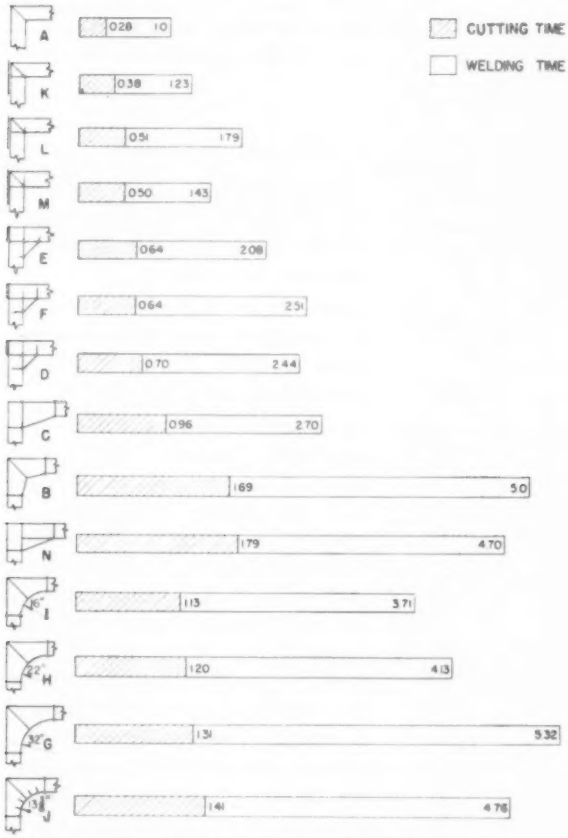


Fig. 1 Bar chart of cutting and welding times[3]

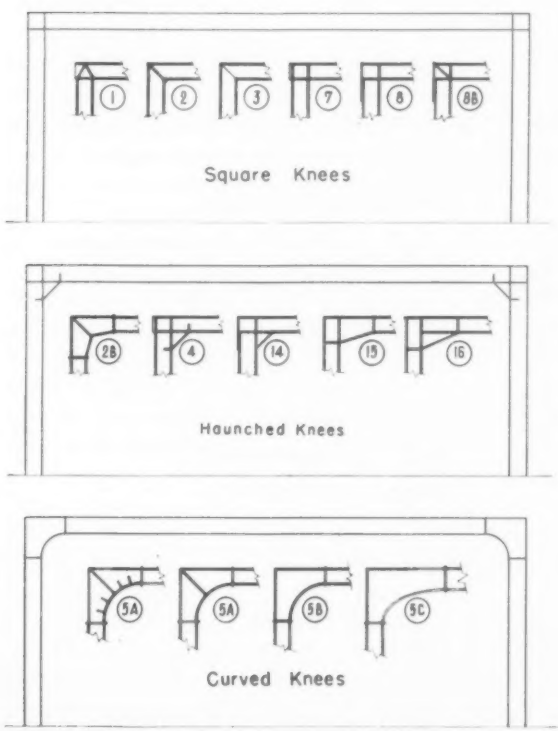


Fig. 2 Classification of portal frame knees[3] *into types*

than 100% rigid (Fig. 3). By omitting structurally unnecessary stiffeners, the fabrication cost of connections of this type could be reduced considerably and made to approach the cost of square knees. Obviously the omission of details such as stiffeners could reduce somewhat the unnecessary margin in strength and rigidity between the rolled shape and the connection.

Square types, which are the least costly to fabricate, although somewhat flexible, show very desirable "rotation capacity." Further investigations to explore other designs of this type has been found in order.

The general objective of the Texas program was to determine the behavior of 11 welded knees. In this respect, it has the same objectives as those of the Lehigh project.[3] Furthermore, this program had the following specific objectives:

(*a*) To determine how much stiffening of Type 4 connections could be omitted without loss in desirable characteristics such as strength, rigidity and rotation capacity.

(*b*) To explore ways by which Type 4 connections could be improved, other than by the use of stiffeners perpendicular to column and beam flanges.

(*c*) To determine whether Type 1, square knee, meets, the requirements of strength and rigidity better than the rest of the knees of the same group.

(*d*) To determine behavior of knees when standard I-shapes are used as rolled sections.

(*e*) To explore the possibility of reducing cost of fabrication by cutting down stiffener lengths, or by omitting stiffeners which may not be needed for strength and rigidity.

II. TEST PROGRAM

The following is a short description of the test program.

1. Test Specimens

The knees tested were of Types 1, 7A, 8B, 5A and 4, as shown in Figs. 4 and 5. These types belong to the square or straight, haunched or bracketed,* and curved knee groups, respectively. In each type a number of alternatives as to details is possible. The Lehigh tests have shown that such fabrication details have a significant effect on behavior.

Two 8B13 rolled members, joined at right angles, formed the basis of five of the connections. Five more connections were fabricated using a 6I12.5 rolled section while in the eleventh connection a 6I17.25 was used. The 8B13 rolled section was chosen because it had been used previously.[3] Due to limited space, the welding details will not be fully discussed here.

* The two terms applied to each of these two types will be used interchangeably in this report.

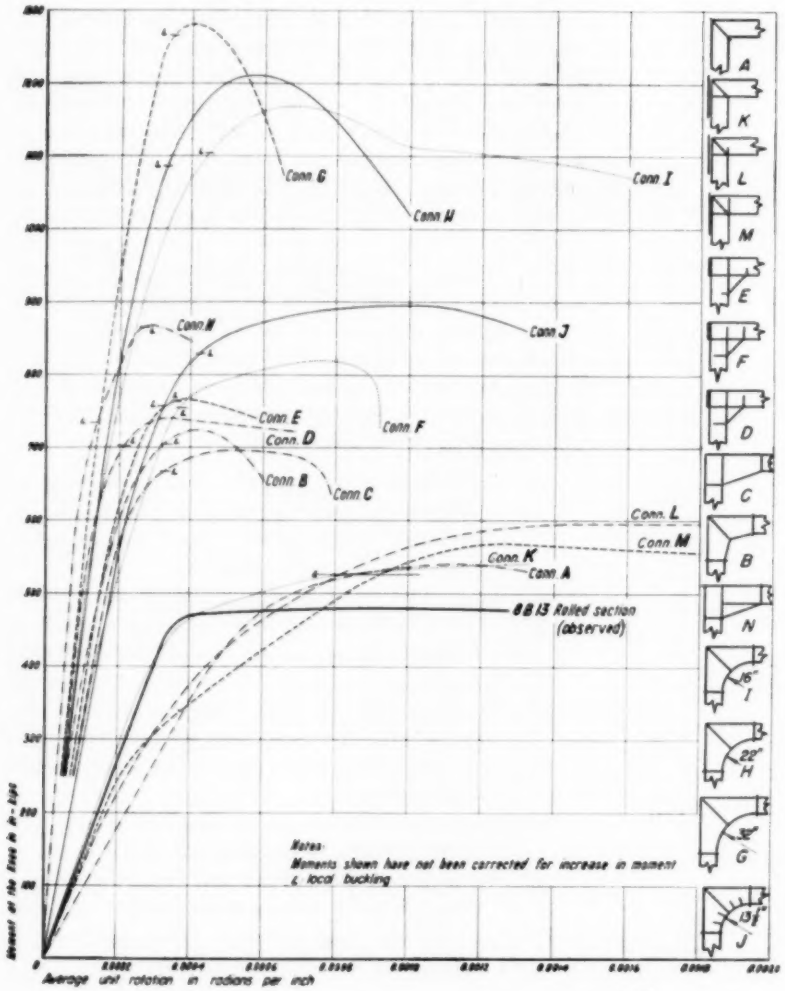


Fig. 3 Connection behavior compared with 8B13 rolled section (based on moment at the knee[3])

2. *Fabrication Details*

Before proceeding with the tests and test results, a short discussion on the structural details of the specimens is in order.

(*a*) *Square Knees.* Connections R-1 and R-2 have 8B13 as-rolled sections, while A, B, C and D have 6I12.5 and E has 6I17.25.

Connections R-1 and R-2 were considered because they were thought to be an improvement over the square types tested in previous programs.[3] The shear stresses induced in the knee web by the tension flange force account for the large rotations shown in some square knees. Rotations in such knees are reduced considerably by the addition of one pair of diagonal stiffeners. These stiffeners cannot, however, prevent shear yield completely; and, as a result, the square knees tested previously were not as rigid as required. Type 1 knee with its two pairs of stiffeners might prove to be more rigid than the rest of the square knees (Fig. 4).

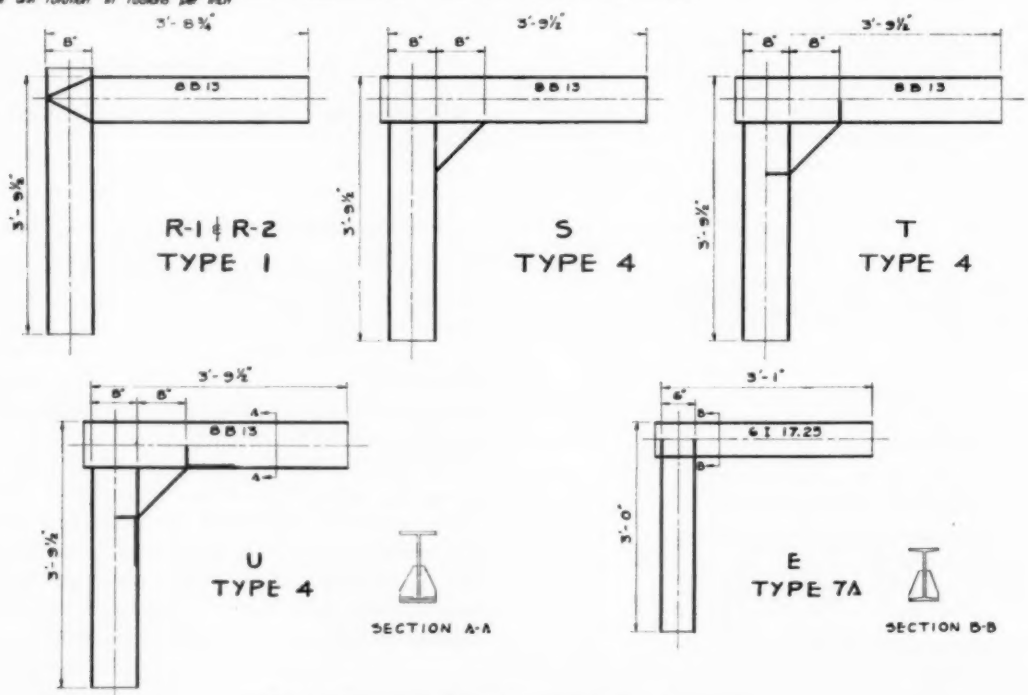


Fig. 4 Connections used in experimental program

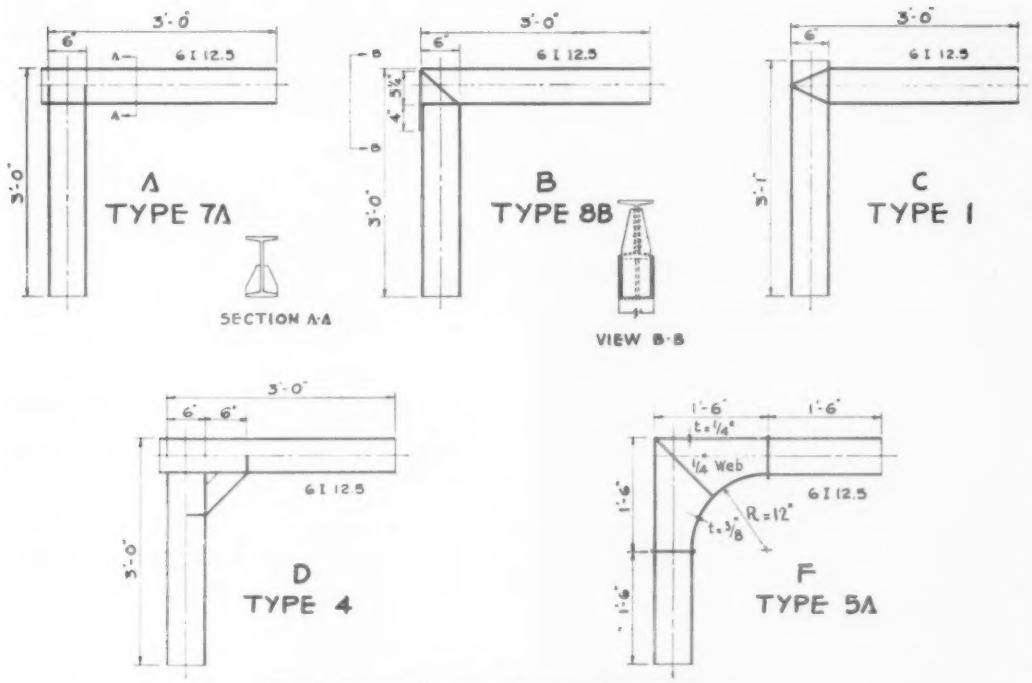


Fig. 5 Connections used in experimental program

Specimen A, Type 7-A, was chosen because of its simplicity. It represented a type frequently seen in actual construction. High shear stresses were expected to develop in the web of the knee. The stiffeners were made half size for economy. Use of full stiffeners could improve only slightly the behavior of this connection (Fig. 5).

Specimen B, Type 8-B, was chosen to observe the effect of a tension plate upon the connection. The diagonal stiffener was added to eliminate partly the high shear stresses in the web of the knee (Fig. 5).

Specimen C, Type 1, had two pairs of diagonal stiffeners to cut down the high shears in the web of the knee. It was thought that this would be an improvement over Specimen B (Fig. 5).

Specimen E, Type 7-A, was similar to Specimen A but fabricated from a 6I17.25. Specimen E was to be compared with Specimen A to observe the effect of the heavier web (Fig. 4).

(*b*) *Bracketed Knees.* These specimens were tested to determine the effect of stiffeners. The vertical stiffeners could be reduced in number since there was ample shearing area in the knee web to resist the tension flange force.

Connections S, T and U have 8B13 as-rolled section, while Connection D has 6I12.5. All the connections in this group are of Type 4.

Specimen S, without any stiffener, is the least expensive connection to fabricate. If it proves to be satisfactory, it could be used instead of the square types (Fig. 4).

Specimen T is similar to S except for the addition of half stiffeners at the two ends of the bracket to distribute to the web of beam and column any concentrated bracket force. The addition of the stiffeners may improve the behavior of the knee (Fig. 4).

Specimen U is similar to T except for the "beefing up" of the inside of the compression flange of beam and column outside the half stiffeners. Such strengthening of the compression flanges with local buckling "arresters" may increase the moment at which local buckling failure of the flange material takes place (Fig. 4).

Specimen D was chosen because it was to be compared with the rest of the connections fabricated with 6I12.5 rolled shape (Fig. 5).

(*c*) *Curved Knees.* Specimen F, Type 5A, was considered mainly for stress analysis purposes; although it is a type frequently used whenever architectural effect is the prime requirement. The inner curve flange of this connection was designed according to AISC "Rules."[1]

III. COST OF FABRICATION

In the Lehigh program, the actual cutting and welding operations were carefully timed to obtain information on the relative cost of fabrication of the various types of knees. The results of these studies are shown in Fig. 1. The bars in this figure represent the actual operations and do not include stops to change position, electrodes, etc.

This system of cost comparison loses some of its meaning unless the same welder and welding procedure is used for every knee. In the Texas program, for exam-

Fig 6 Connection S—Test setup and instrumentation in 400,000-lb machine used for all tests. Note the rotation measuring device, the deflection gage support and the lateral support bars

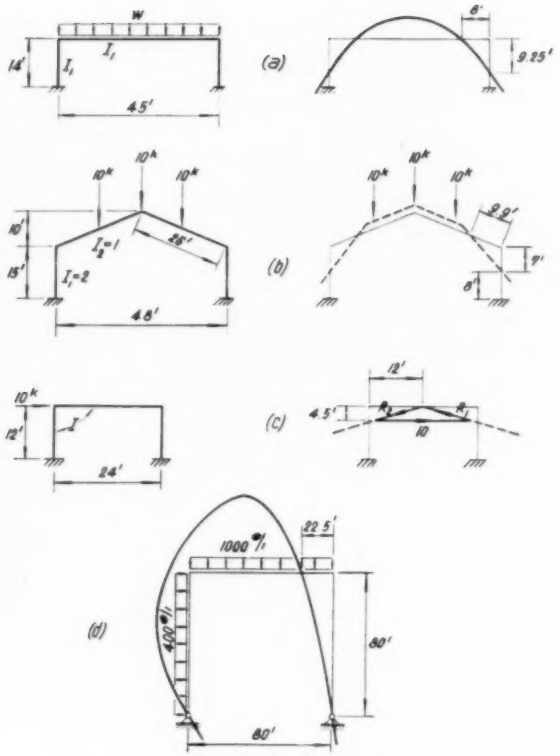


Fig. 7 Load lines

ple, four different welding operators had to be used. Therefore the time data obtained during the fabrication of these specimens cannot be presented, since it may not be reliable. However, it should be added here that the fabrication times for specimens S, U, R-1 and R-2 were so close that they may be assumed to be equal.

IV. TEST APPARATUS AND TEST PROCEDURE

All the connections used in this program were tested in 400,000-lb screw-type machine. Figure 6 illustrates the method of loading.

1. Type of Loads

Figure 7 illustrates some frames, together with their Load or Pressure Lines resulting from various kinds of loadings. The knees are always under "compression" for gravity loads. The Pressure Line due to lateral load on a frame is shown in Fig. 7 (*c*). Such a load results in moments of opposite signs at the two knees of the frame; it is then said that one of the knees is under "tension" forces. The "compression" type of loading was used in the program reported herein.

The specimen was placed in the testing machine with the legs making an angle of 45 degrees with the horizontal. A plumb bob and tape were used to secure proper alignment and centering of the connections, both vertically and laterally. The loads were applied through round bars welded at the ends of the specimens.

2. Lateral Support

Although there was no danger of elastic buckling of the connections, lateral supports were provided because once yielding starts, the lateral buckling strength of the specimen is reduced. In order both to prevent lateral buckling from bringing about early failure and at the same time to furnish no restraint to vertical or longitudinal displacement of the connection during all stages of loading, two pairs of flexible bars between the knee and a rigid support were used. The location of one pair of these bars may be observed clearly in Fig. 6. These flexible bars were anchored on two 8WF17 beams which were clamped to the outside of the testing machine columns at the level of the knee. The locations of attachment of the two sets of lateral support bars are shown in Fig. 8. These lateral support bars were also used to measure the lateral forces. To do this, two straight SR-4 gages were attached to each of the bars which joined the knee at Points *A* (see Fig. 8).

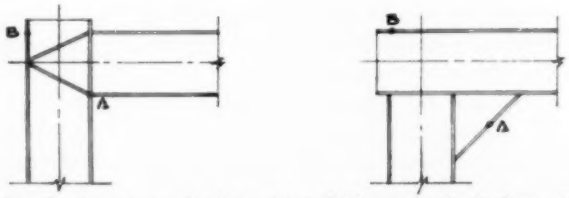


Fig. 8 Points on the knee (A and B) at which the lateral support bars were attached

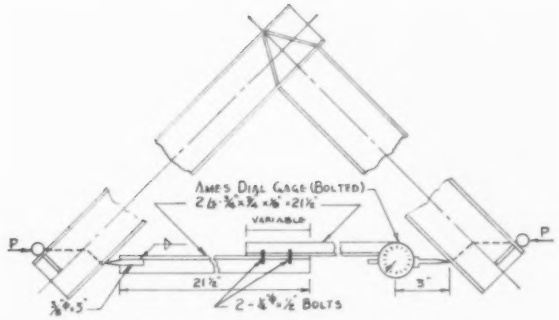


Fig. 9 Deflection gage support

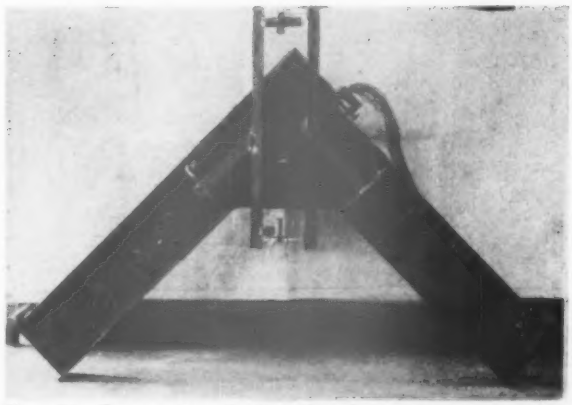


Fig. 10 Connection S—Details of rotation measuring device

3. *Measurements*

Deflections were observed in every connection for all loads by measuring the change in length of vertical line through each leg of the connection parallel to the load line. This was done by making a punch mark in each leg of the specimen and placing the pointed ends of the deflection gage support in the hole thus made (Fig. 9).

Relative rotations in each knee were measured with a rotation measuring device illustrated in Fig. 10. Any change in angle (rotation) of the knee was reflected as a change in angle between the bars of the rotation device.

Strain measurements were made with SR-4 gages on the stiffeners and flanges of specimen R-2 and in the flanges and web of specimens F and S. Each knee was whitewashed so that the flaking of mill scale that followed the formation of Luder's lines at the yield point was easily observed.

4. *Test Procedure*

Prior to the actual test and following the "friction" test the lateral support bars were tensioned to about 300 lb. In the elastic range, load increments of approximately 2 kips were used, while in the plastic range the size of increment was reduced generally to about 1 kip.* As each load was balanced, readings were taken for deflection, rotation and strain gages; and yield lines were observed and their locations recorded. After yielding occurred, readings were taken according to a criterion which assured that all significant plastic flow had taken place under constant load prior to the recording of data. For this program the "criterion" was 0.0030 in. of deflection in 15 minutes as indicated by the deflection dial gage, the load being maintained constant.

V. TEST RESULTS

The test results will be presented under three different main headings according to the size of the rolled sections used. In each of the three main divisions the test results of the various types will be given.

* Connections R-1 and F were unloaded and reloaded once, while for Connection U the unloading and reloading cycle was repeated twice. The data for these cycles is not presented because such unloading and loading did not alter the behavior of the knees.

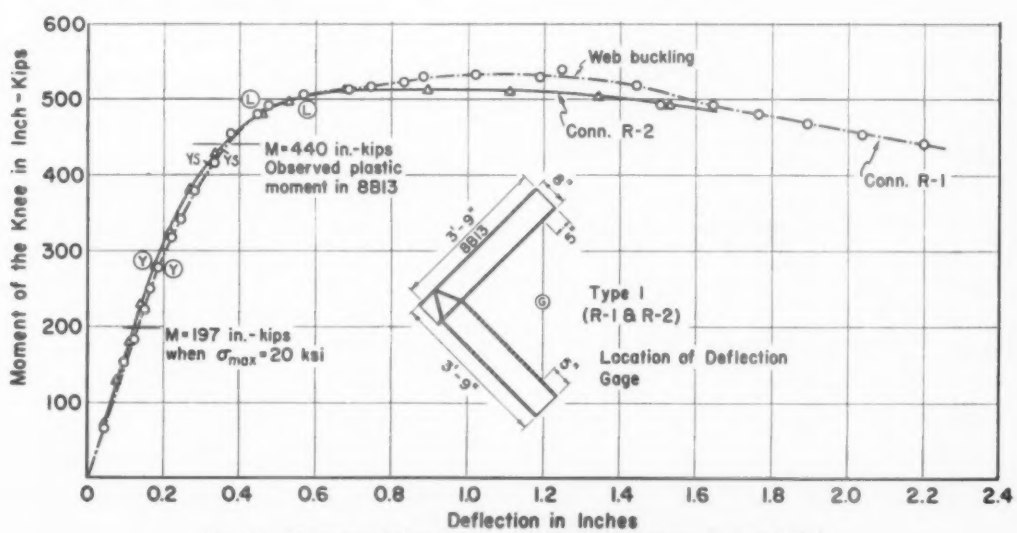


Fig. 11 Moment-deflection curves for Connections R-1 and R-2

Fig. 12 Connection R-2—Yield lines at the end of test. Extensive local buckling deformation in compression flange evident

Fig. 13 Connection R-2—Yield line in flanges and stiffener. Local buckling which is unsymmetrical caused final collapse

1. Knees with 8B13 Rolled Section

(*a*) *Square Knees (Connections R-1 and R-2, Type 1).*

Strength: This important requirement for connections may best be examined with moment-deflection curves. In Fig. 11 the moment-deflection curves for the two connections of this type are shown . Moment at the knee is computed about the point of intersection of the neutral axes of beam and column, the deflections being measured with an Ames dial as shown. The moment at which a theoretical stress of 20 ksi is reached at the face of the knee (critical section) is shown on the curves. It should be noted that the connections carried more than $2^1/_2$ times the moment for 20 ksi. Another point plotted on the curves is the observed maximum moment for 8B13. Both connections have developed moments larger than 440 in.-kip.

Stiffness: This is another important requirement which will be discussed below, together with Type 4 connections.

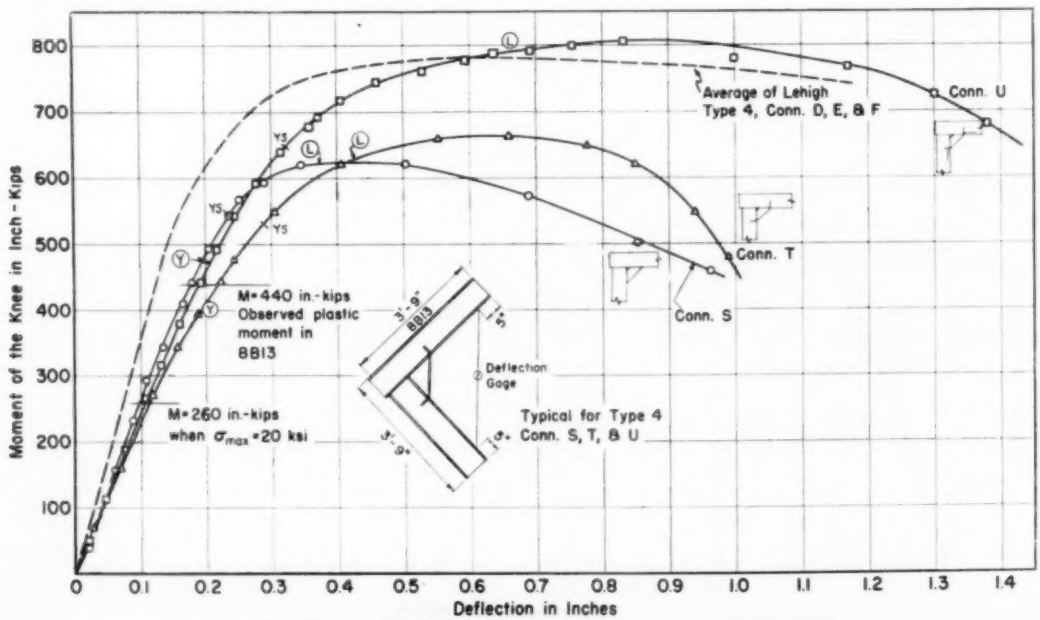


Fig. 14 Moment-deflection curves for Connections S, T and U

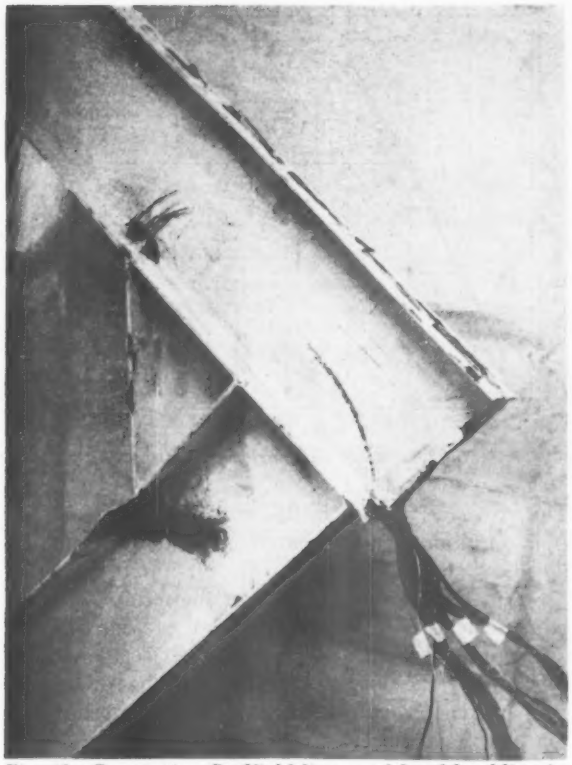


Fig. 15 Connection S—Yield lines and local buckling in column flange. End of test

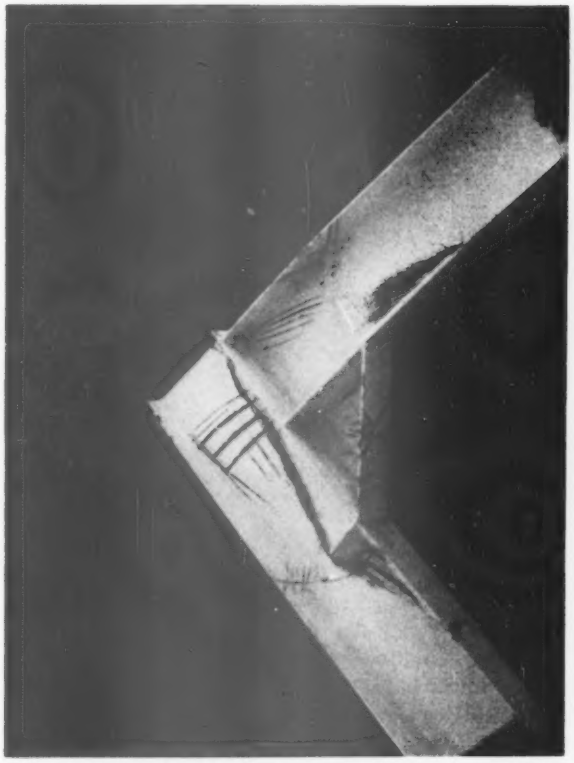


Fig. 17 Connection U—Extensive yielding evident. Effect of "beefing up" of compression flange with local buckling arresters evident. Note location of local buckling

Yielding and Mode of Failure: At a moment of about 275 in.-kips (about 52% of maximum moment) the first yield line appeared at the reentrant angle area. This yielding apparently affected the behavior of the connections since the deflection curve started deviating from a straight line at about 300 in.-kips (about 57% of maximum moment). Figures 12 and 13 show Connection R-2 at the end of the test (note the buckling of the compression flange). This local buckling started at about 500 in.-kips.

(*b*) *Haunched Knees* (*Connections S, T, and U, Type 4*).

Strength: In Fig. 14 the moment-deflection curves of the Type 4 connections are shown. Plotted on the curves is the moment to produce maximum stress of 20 ksi at the end of the rolled section. The connections surpassed this moment by 220–310%. The moment developed at the knee is larger than $M = 440$

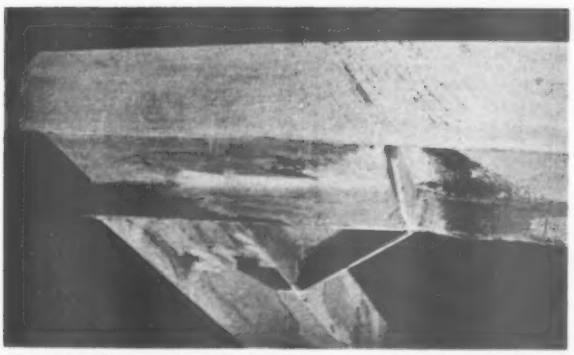


Fig. 16 Connection T—Yielding at end of test. Local buckling evident in the beam compression flange

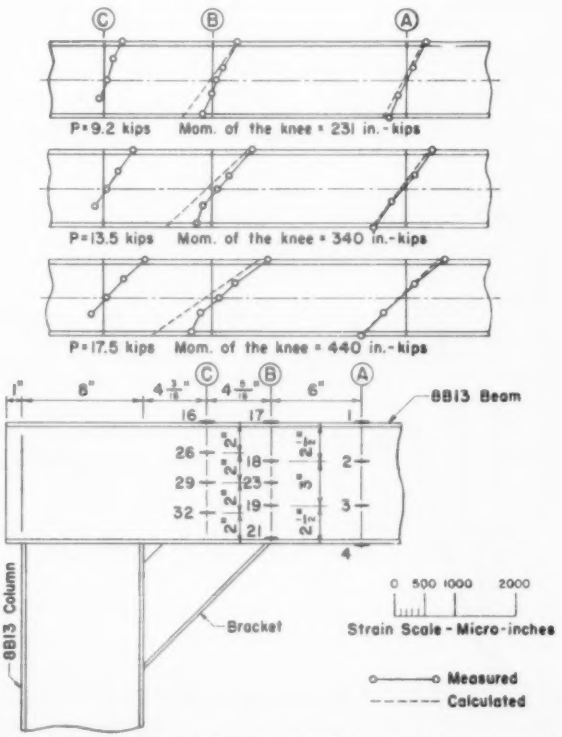


Fig. 18 Normal strain distribution in beam of Connection S

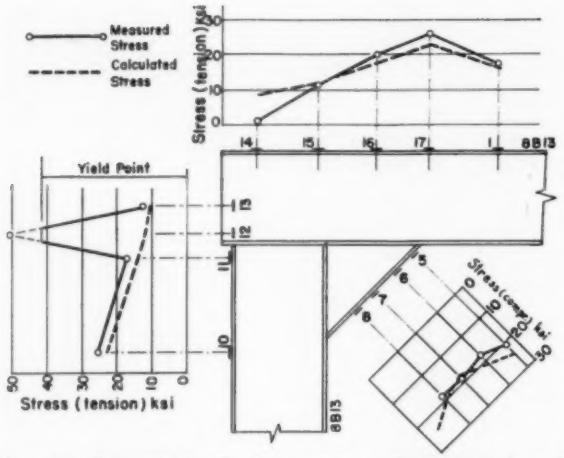


Fig. 19 Connection S—Comparison of measured and calculated stresses (P = 17.5k)

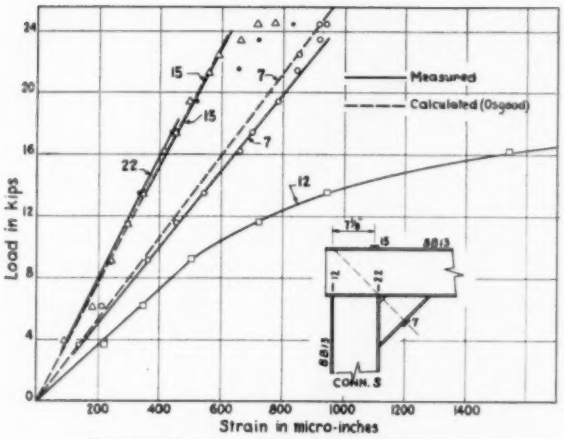


Fig. 20 Strain comparisons, Connection S

in.-kips, the plastic moment of 8B13, which is also indicated on the curves. Of the three designs, Connection U is the strongest while Connection S is the weakest.

Yielding and Mode of Failure: First yield lines were observed at about 400 in.-kips (60% of maximum moment) for Connection T, and at about 475 in.-kips for Connections S and U (82 and 58% of maximum moment, respectively). Figure 15 shows Connection S at the end of the test. The yield lines developed may be clearly seen. Local buckling of the compression flange for this connection started at about 575 in.-kips. Figure 16 illustrates the yield lines and local buckling of the compression flange of Connection T. Figure 17 is a picture of Connection U at the end of the test. The extensive yielding in this specimen, as well as the effect of reinforcing the compression flanges, should be noted.

Strain Distributions: Some of the results of strain measurements for Connection S are presented. The distribution of normal strains and their comparison to calculated values is shown in Fig. 18. The variation of strains along the flanges and the haunch are shown in Fig. 19. The calculated values for strains are based on a solution given by Osgood.[6] Figure 20 further illustrates the agreement between calculated and experimental strains.

Rigidity: The rigidity of both Type 1 and Type 4 connections (8B13) will be studied by reference to Fig. 21, which also summarizes their behavior. The average unit rotation is obtained by dividing the total meas-

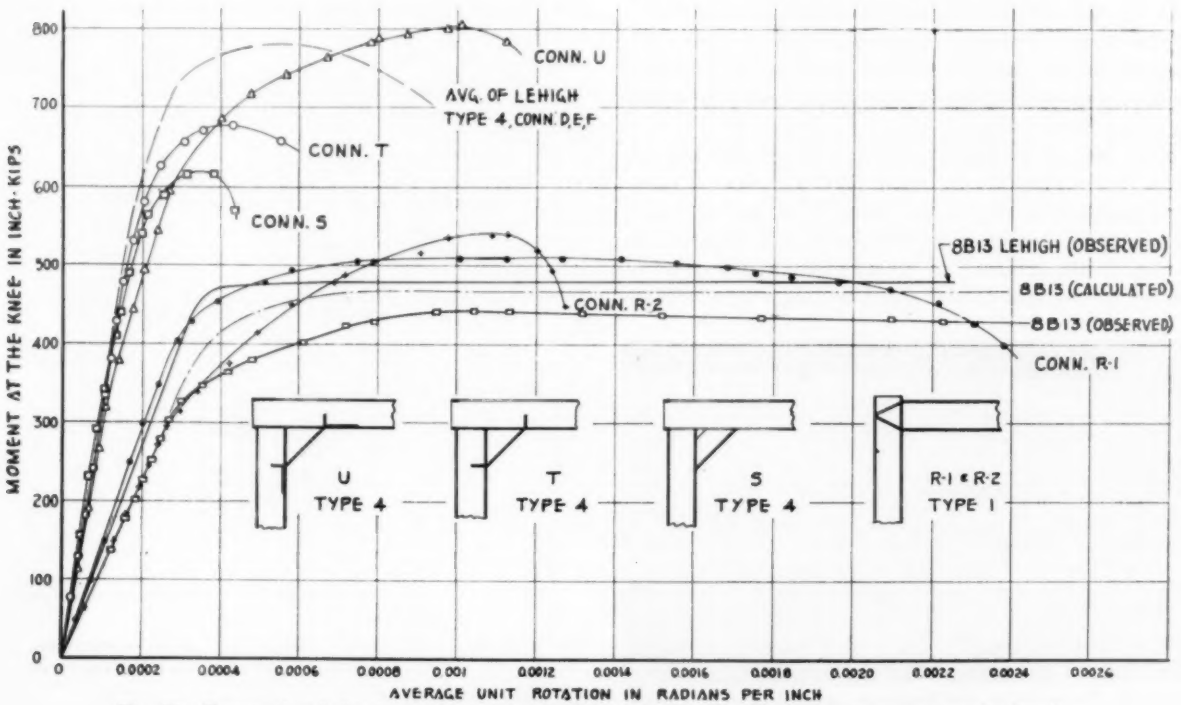


Fig. 21 Connection behavior compared with 8B13 rolled section (based on moment at the knee)

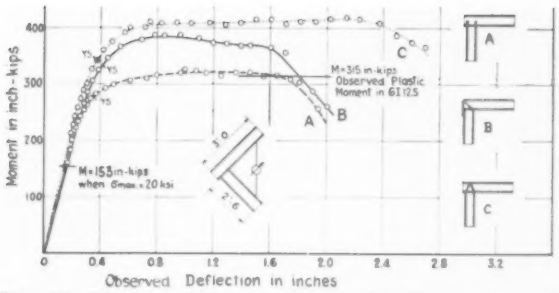


Fig. 22 Moment-deflection curves for Connections A, B and C

ured rotations in the knee by the equivalent length of each knee. The unit rotations thus computed are compared to the unit rotations measured in the rolled 8B13 section.

The Type 1 connections have shown rigidities, in both the elastic and plastic ranges, which are satisfactory. When Fig. 11 is compared with 21, it becomes apparent that the sudden drop in the rotation for Connection R-2 is not due to the over-all behavior of the connection, but rather to a malfunctioning of the rotation device. This could be due to excessive yielding and local buckling deformation near the point where the rotation device was attached.

The behavior of the three Type 4 connections is also summarized in Fig. 21. (Note the closeness of the curves in the elastic range.) Connection U has developed higher strength than the average of the Lehigh Type 4 connections.

2. *Knees with 6I12.5 Rolled Section*

(*a*) *Square Knees (Types 7A, 8B, 1).*

Fig. 23 Connection A—Yield lines at end of test. Length of crack caused by weld failure can be easily seen

Fig. 24 Connection A—Yield lines and weld failure after collapse. Extensive yielding of knee web evident

Strength: In Fig. 22 are shown the moment-deflection curves for connections A, B and C. Two points for comparisons are also drawn, i.e., the moment for a maximum fiber stress of 20 ksi and the observed maximum moment for 6I12.5. Of the three connections, Type 1 develops the highest strength.

Yielding and Mode of Failure: Connection A—The first yield lines appeared at 205 in.-kips and were located in the web of the beam. The amount of yield at the knee and in the beam and column are shown in Fig. 23.

At 321 in.-kips, a failure started developing at the weld between beam and column at the tension side. The failure was of a "pull-out type" as shown in Fig. 24. At 324 in.-kips, local buckling was noticed on the south side of the compression flange of the beam. Connection A supported a maximum moment of 324 in.-kips.

Connection B—The first yield line appeared in the web of the beam at 122 in.-kips. A crack appeared at 387 in.-kips in the weld at the top end of the tension plate (Fig. 25). The specimen supported decreasing loads as the crack propagated and widened. Figure 26 is a view of Connection B showing the crack. (Note the curvature in the diagonal stiffener.)

Connection C—Yield lines appeared at 275 in.-kips. Figure 27 shows connection at the end of the test. The north-side tension stiffener weld cracked at the lower end at approximately 390 in.-kips.

Rigidity: In Fig. 28 the connection rotations (A, B, C) are compared to the observed moment-rotation curve for the 6I12.5 rolled section. All three connections developed strengths higher than the rolled sections

Fig. 25 Connection B—Yield lines at end of test. Local buckling of compression flange not extensive. Crack in the knee web starting at the tip of end tension plate visible

Fig. 27 Connection C—Weld failure at the lower end of tension stiffener at end of test

but their stiffnesses were lower. Only Type 1, Connection A, developed rigidity almost equal to 6I12.5.

(*b*) *Haunched and Curved Knees* (*Connections D and F*). The behavior of these two connections will be studied by means of their moment-rotation curves (Fig. 28).

Strength, Rigidity and Mode of Failure: Connection D—The ultimate moment carried by this specimen was 535 in.-kips. This connection was more rigid than an equivalent length of 6I12.5 rolled section. The first yield line was observed at 204 in.-kips. Figure 29 shows the yield lines at the end of the test. (Note the twisting of the beam which took place near the completion of the test.) Local buckling of the north compression flange of the column was first observed at 534 in.-kips. Later, more extensive buckling occurred on the south compression flange of the beam.

Connection F— The location of the early yield lines which occurred at 224 in.-kips is shown in Fig. 30. Figure 31 shows the connection at the end of the test after it was stripped and ready to be removed. The effectiveness of the lateral bars (and the S-shape of the connection) should be noted. Figure 32 shows the extensive yielding that has taken place in Connection F. (Note the buckling of both curved flange and of the web, and the yield lines at the end of the rolled section.) This connection, as expected, developed the highest strength and rigidity, when compared with the other connections.

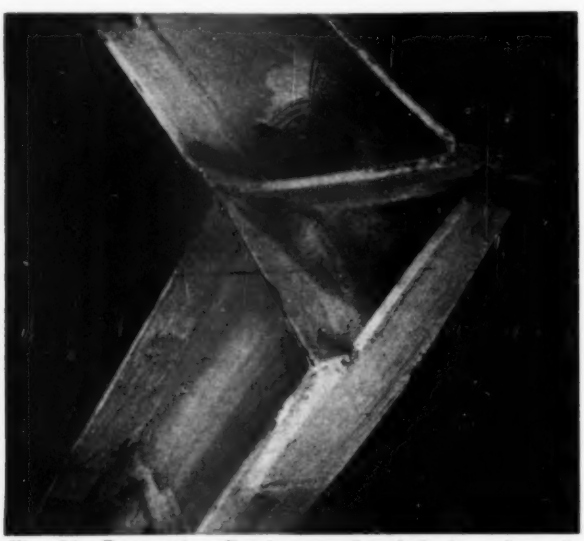


Fig. 26 Connection B—A more detailed view of crack developed. End of test

3 Knees with 6I17.25 Rolled Section

(*a*) *Square Knee* (*Type 7A*). In Fig. 33 the moment-rotation curve of the Connection E and that of the 6I17.25 are compared. Although the connection has developed sufficient strength, it is less rigid than its rolled section. The first yield line appeared at 152 in.-kips. Figure 34 shows how far out yielding proceeded both in the beam and column. Very slight local buckling was observed at 363 in.-kips. The com-

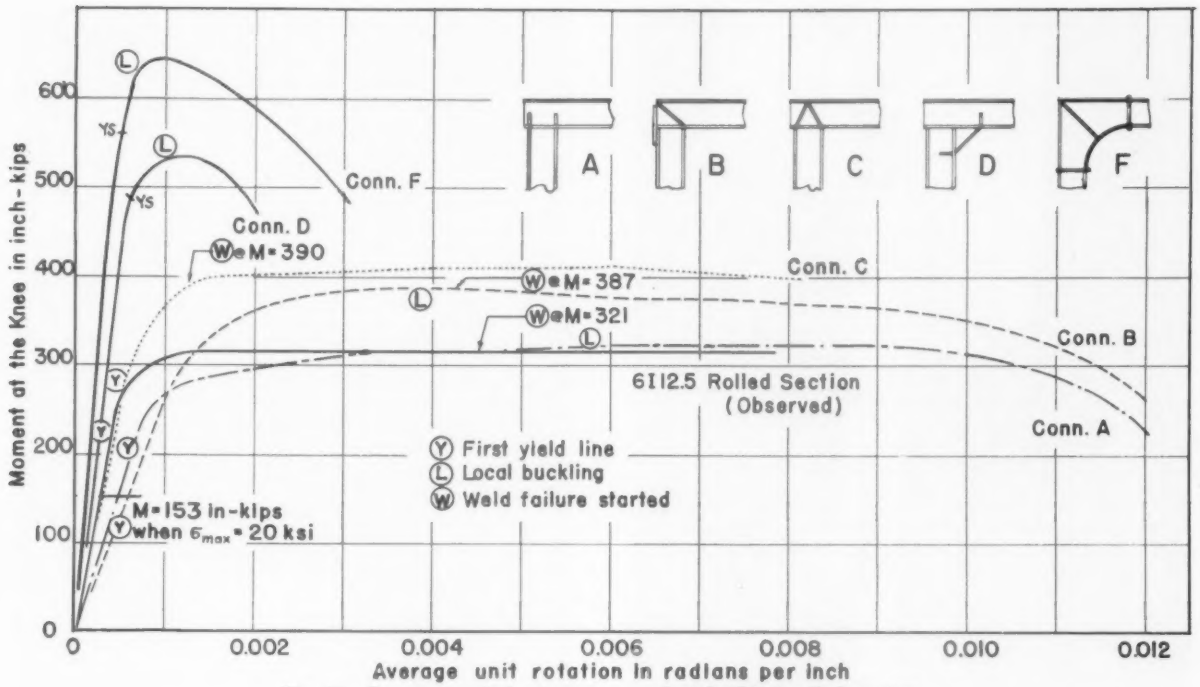


Fig. 28 Connection behavior compared with 6I12.5 rolled section

pression flange on the north side of the beam continued to buckle at a very slow rate.

When the rotation reached 0.00748 rad/in. the lateral support bars were removed because of large deflections and the test completed without lateral restraint.

4. *Lateral Restraining Forces*

Figure 35 shows the variation of the forces required to keep Connections R-1 and C from buckling laterally. The maximum lateral force developed for both knees was about 3 kips., which was a small fraction of the load applied to the connection. The lateral forces increased very rapidly after local buckling started.

VI. SUMMARY OF TEST RESULTS

Table I summarizes the following information on the strength of each connection:

(*a*) Observed moment at formation of first yield line (yield line moment).

(*b*) Observed general yield and computed initial yield.

(*c*) Maximum moment M_h, in the knee.

(*d*) Maximum moment M_r, at the end of rolled section.

Figures 21, 28 and 33 summarize the moment-rotation data for connections fabricated with 8B13, 6I12.5 and 6I17.25, respectively. Figures 18, 19 and 20 present measured strains in Connection S and the comparison of these to calculated strains.

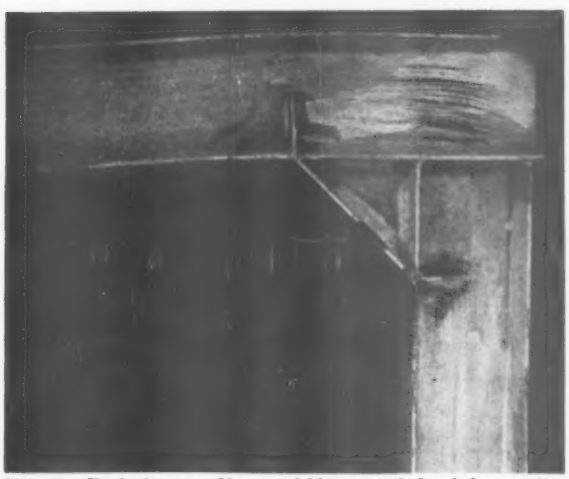


Fig. 29 End of test. Note yield lines and the deformation of the beam

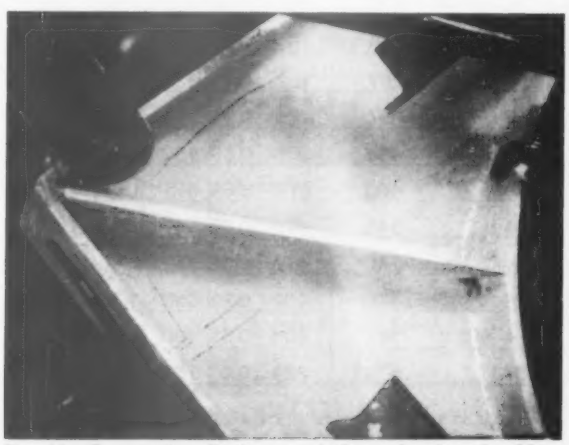


Fig. 30 Connection F—First yield lines developed. M_h = 326 in.-kips. Connection at failure shown in Fig. 32

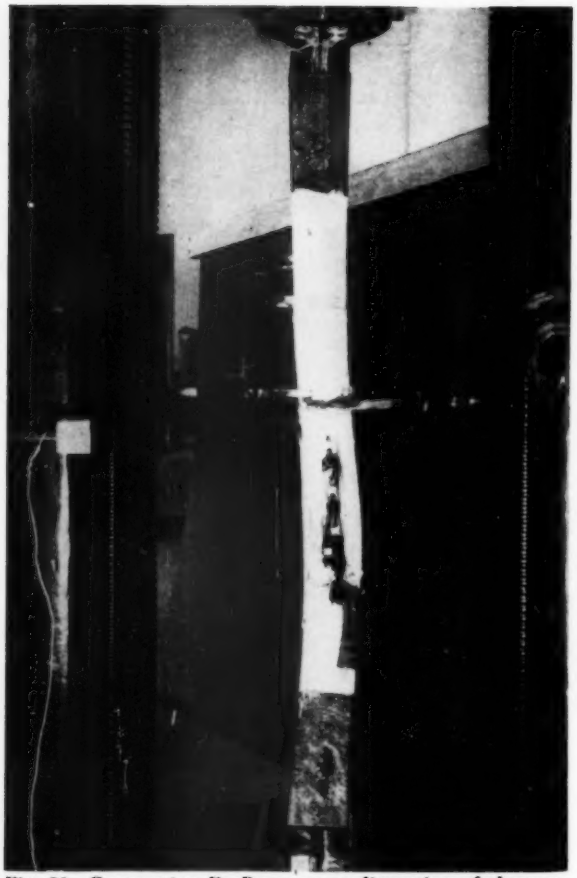


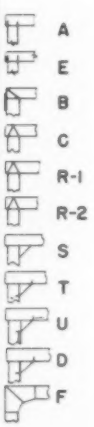
Fig. 31 Connection F—Permanent distortion of the connection at end of the test. Lateral support adequate to cause S-shaped collapse

Fig. 32 Connection F—Extensive yielding and local buckling of curved flange evident. Web in the same area buckled also

Table 2 lists the photographs and moment-deformation curves for the various knees of this program.

Table 1—Comparison of Observed and Calculated Moments

CONNECTION (1)	TYPE (2)	ROLLED SECTION (3)	COMPUTED INITIAL YIELD MOMENT $M_{h(i)}$ (4)	YIELD LINE MOMENT		GENERAL YIELD MOMENT		MAXIMUM MOMENTS						
				Observed $M_{h(1)}$ (5)	$\frac{M_{h(1)}}{M_{h(i)}}$ (6)	Observed $M_{h(3)}$ (7)	$\frac{M_{h(3)}}{M_{h(i)}}$ (8)	Computed Plastic Hinge Moment $M_{p(com.)}$ (9)	Observed Plastic Hinge Moment $M_{p(obs.)}$ (10)	Observed Max. Moment @ Knee $M_{h(4)}$ (11)	$\frac{M_{h(4)}}{M_{p(com.)}}$ (12)	$\frac{\text{Max. } M_h}{M_{p(obs.)}}$ (13)	Obser. Max.++ Moment $M_{r(4)}$ (14)	$\frac{M_{r(4)}}{M_{p(obs.)}}$ (15)
A	7A	6I12.5	203+	205	1.02	275	1.36	330	315	324	0.98	1.03	290	0.92
E	7A	6I17.25	359	152	0.42	353	1.02	418	–	482	1.18	–	431	1.03**
B	8B	6I12.5	297	122	0.41	330	1.11	330	315	387	1.17	1.23	346	1.10
C	I	"	297	275	0.93	340	1.14	"	"	413	1.25	1.31	370	1.18
R-1	I	8B13	406	276	0.68	430	1.06			540	1.16	1.23	480	1.09
R-2	I	"	406	278	0.69	415	1.02			508	1.09	1.15	451	1.02
S	4	"	540	475	0.88	540	1.00	466	440	620	1.33	1.41	408	0.93
T	4	"	540	475	0.88	530	0.98			673	1.44	1.53	443	1.01
U	4	"	540	492	0.91	650	1.20			806	1.73	1.83	532	1.21
D	4	6I12.5	382*	204	0.55	490	1.28	330	315	535	1.62	1.70	364	1.15
F	5A	"	579*	224	0.39	560	1.06	"	"	642	1.95	2.04	303	0.96



+Based on shear in the web of the knee.
++Observed max. moment at the junction of knee and rolled section.
*Based on moment to yield rolled section at end of knee.
**Based on M_p = 418 in-kips, calculated plastic hinge for 6I17.25.

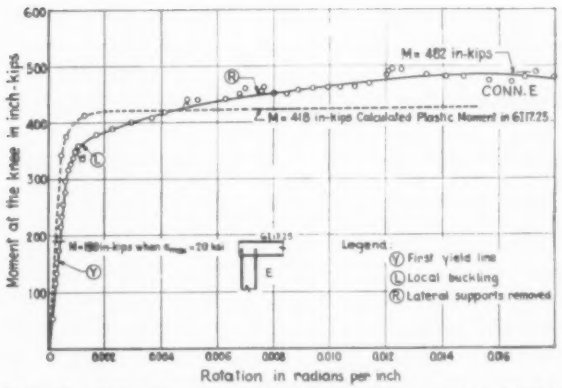

Moment at the knee in inch-kips
Rotation in radians per inch
M= 482 in-kips
CONN. E
Z M= 418 in-kips Calculated Plastic Moment in 6I17.25
Legend:
Ⓨ First yield line
Ⓛ Local buckling
Ⓡ Lateral supports removed

Fig. 33 Connection E behavior compared with 6I17.25 (calculated)

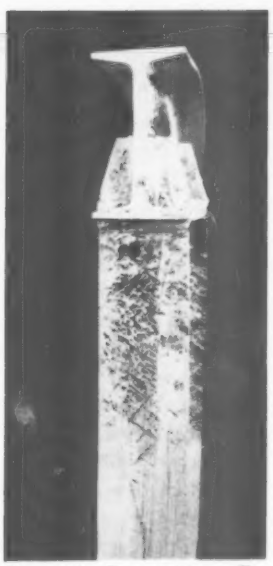


Fig. 34 Connection E—Yield lines on the tension flange of column. End of test. Permanent deformation in knee visible

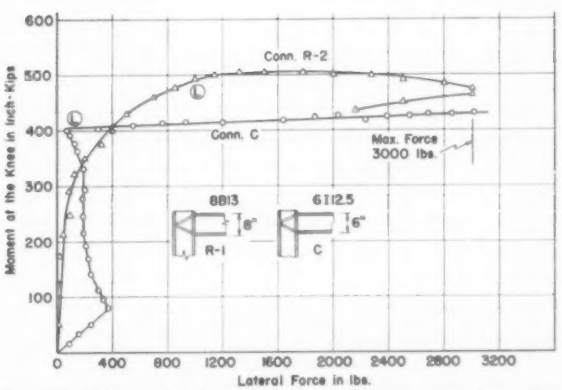


Fig. 35 Moment-lateral force curves, Connections R-1 and C, Type 1

Table 2—Figure Numbers for the Various Knees

Connection	*Photographs*	*Moment-Deformation Curves*
A	23, 24	22, 28
B	25, 26	22, 28
C	27	22, 28
D	29	28
E	34	33
F	30, 31, 32	28
R-1	...	11, 21
R-2	12, 13	11, 21
S	15	14, 21
T	16	14, 21
U	17	14, 21

VII. DISCUSSION OF TEST RESULTS

The test results for each of the types tested will be discussed, and items such as strength, rigidity and mode of failure will be reviewed.

Square Knees

(*a*) *Type 7A (Connections A and E).* Connection A, as compared with the 6I12.5 rolled section, proved to be less rigid. As such, its structural behavior was similar to the Type 7, Connection P of Lehigh (fabricated with 8WF31 and 14WF30), with the exception that it did develop a maximum moment at the knee higher than the observed plastic hinge moment of 6I12.5. However, it failed to develop the same moment at the end of the rolled section.

This connection yielded in shear at the knee web when M_k equaled 205 in.-kips. The moment for such initial yielding has been calculated by means of the expression $M_{k(y)} = \dfrac{\sigma_{ys} w d^2}{2(1-d/L)}$ *, [4] and found to be 203 in. kips.

Connection E proved to be also less rigid when compared with 6I17.25 (calculated). It developed strength higher than the 6I17.25 both at the knee and at the end of the rolled section (see Table 1). Theoretically this knee should yield at the end of the rolled section. The first yield line appeared in the web of the knee, however, possibly due to residual stresses. An idea of the amount of yielding that occurred in Connections A and E can be formed from Figs. 23 and 34. In A, extensive yielding took place in the web of the knee, while in E not only did the knee web show large yielding but also the flanges yielded as far away as twice the depth of the 6I17.25 section from the end of the knee. The rotation capacity of both knees is good because of the suitable local buckling characteristics of the Standard I shapes. The extent of local buckling was much less on Connection E than it was on Connection A. In general, less deformation resulted from local buckling with the Standard I shapes than it did with the wide flanges. The flange width and thickness of 6I12.5 is equal approximately to that of 6I17.25. The web of the 6I17.25

* Nomenclature and terminology same as in Reference 4 also.

is, on the other hand, twice as thick as the web of the 6I12.5. Therefore the web of the former offers more restraining force than does the web of the latter. This fact is evidenced by the test results of Specimen E in which, in spite of considerable yielding, local buckling deformation of the compression flange was not excessive.

The lateral support bars had to be removed during the test of Connection E (Fig. 33). Even without lateral support this connection carried the maximum moment through large deformations, a performance very desirable where energy loads are to be absorbed. The two connections finally collapsed due to excessive yielding and deformation (Figs. 23 and 34), with the exception that a weld failure developed in Connection A at the junction of the tension flange of column and the beam (Fig. 24). This failure was probably due to incomplete penetration and lack of fusion. As the crack—that opened because of the weld failure—increased in width the specimen's load carrying capacity was materially reduced.

(*b*) *Type 8B* (*Connection B*). In Fig. 28 the structural behavior of Connection B is compared with that of 6I12.5 rolled section. This connection did not prove to be as rigid as the rolled section. "B" carried, however, moments at the knee and at the end of the rolled section higher than either the calculated or the observed plastic hinge moment of the 6I12.5 rolled section (Table 1 and Fig. 29). At about the maximum moment, and after local buckling started, a crack developed in the web of the knee at the tip of the tension end plate. The crack propagated along the weld between the diagonal stiffener and the web. This failure pointed out that the design of the knee (the length of the tension end plate having been cut to reduce cost of fabrication) was faulty (Fig. 26).

(*c*) *Type 1* (*Connections C, R-1 and R-2*). Connection C proved to be almost as rigid as the 6I12.5 rolled section. From the strength point of view, it carried moments both at the knee and at the end of the rolled section which were higher than the plastic hinge value of 6I12.5 (computed and observed). The high strength exhibited by this connection was developed in spite of the fact that a weld failure occurred on one of the tension stiffeners (Fig. 27). The weld failure which was due to incomplete penetration and lack of fusion did not influence the behavior of the connection seriously.

Connections R-1 and R-2 developed strength and rigidity higher than that of the 8B13 rolled section used in these connections (Fig. 21). Both specimens developed the observed plastic hinge moment of the rolled section at the knee and at the end of the rolled section. Considerable yielding took place in the web and flange of the rolled section outside the knee (Figs. 12, 13). The ultimate collapse of these connections was due to unsymmetrical local buckling of the compression flange which finally caused the buckling of the web and lateral buckling.

The connections (C, R-1 and R-2) also showed good rotation capacity, high strengths and rigidities; therefore, they proved to be the best of the square knee types.

Bracketed Knees. (Type 4: Connections D, S, T and U)

Connection D, which was tested to show its suitability, developed higher rigidities than did the 6I12.5 rolled section as well as considerably higher moments than the rolled section both at the knee and at the end of the rolled section. Yield lines first appeared in the knee web and then spread (Fig. 28). The ultimate failure was due to local buckling.

Connections S, T and U developed higher strengths in the same order of sequence. Connection S, which has no stiffeners at all, developed the plastic hinge moment (calculated and observed) of 8B13 at the knee but failed to develop the same moment at the end of the rolled section. Connections T and U developed the hinge at both places. All three of the connections, furthermore, show stiffnesses and strengths higher than those of the Lehigh 8B13 rolled shape.* From Fig. 21 it is obvious that the addition of stiffeners does increase the strength and rigidity, but that such additional amounts of the latter are not necessary. The only really beneficial effect of stiffeners seems to be in the increase of the rotation capacity of the knee. Figure 21 illustrates that Connection U, with its additional stiffeners, has the best rotation capacity of the three. The rotation capacity of all three could have been larger with a better lateral support. This subject and others have been fully covered in Reference 5 and need not be repeated. Strain distributions for Connection S as measured with SR-4 gages is shown in Figs. 18, 19 and 20. These results show that normal stresses along the flange of the knee could be calculated by means of a method developed by Osgood.[6] Figure 20 illustrates the comparison of calculated and observed strains at certain points. This figure makes it rather plain that the interior stiffener (continuation of column compression flange) is useless. There could be a place for a half stiffener, though, on the tension side of the column (see gage 12, Figs. 19 and 20).

Curved Knees. (Type 5A: Connection F)

This connection proved to be stiffer and stronger than all other connections fabricated with 6I12.5 rolled section (Fig. 28). However, its rotation capacity is small. This could be improved with better lateral support and additional stiffeners or thicker curved flanges.

Further Research

Based on the results obtained from both the Texas

* The section properties of the various rolled shapes are given in Appendix I.

and Lehigh programs the following investigations are recommended:

1. Further investigation of Type 1 and Type 8B square knees. Such a program should also make a thorough experimental exploration of the stress distributions in flanges, web and stiffeners in the knee, with emphasis on stiffeners.

2. Future investigation of the possibility of a square knee with a half stiffener in line with the compression flange of column or beam, and a diagonal stiffener in tension. Such a stiffener could transfer the tension flange forces much more efficiently than can the usual stiffener which is under compression.

3. Finally, initiation of a program of fatigue testing of connection for welded portal frames. The results of the Texas and Lehigh investigations proved that welded connections could be fabricated economically to meet requirements of strength and rigidity when subjected to static loads. However, a program in which the connections are subjected to repeated cyclic loading seems to be in order.

VIII. CONCLUSIONS

The following conclusions are based on the results of the tests described:

(*a*) The amount of welding in Type 4 connections (and consequently the cost of fabrication) can be reduced by simplifying fabrication details, such as the omission of structurally unnecessary stiffeners.

(*b*) Type 4 connections without any stiffeners at all (Connection S) meet the requirements of strength and rigidity but have small rotation capacities. The latter could, however, be increased with the addition of stiffeners.

(*c*) Type 4 connections with wide flange rolled sections will show a better performance if the compression flanges of beam and column are reinforced by plate material welded to the flanges beyond the junction of rolled section and knee (Connection U). Efficient lateral support will also improve the performance of such connections.

(*d*) Square knees of Type 1 meet the requirements of strength, rigidity and rotation capacity. Other types of square knees, however, did not prove to be rigid in the elastic and the early part of the plastic range.

(*e*) Knees fabricated with 6I12.5 and 6I17.25 behaved the same way—except for their increased resistance to local buckling because of thicker flanges and webs in the standard I-shapes—as those fabricated from wide flanges.

(*f*) Weld failures can result if knees are not welded or designed properly. The need for qualified experienced welders can not be overemphasized. A great deal more attention must be paid to welds under tension than those under compression stresses. Bevel welds should be given preference over fillet welds if possible.

(*g*) Strains in bracketed and curved knees can be calculated to an acceptable degree by approximate methods, based on wedge theory.

IX. ACKNOWLEDGMENTS

The writer wishes to express his appreciation to S. R. Halver, B. D. Campbell and L. P. Johnston who carried out 8 of the 11 tests described in this report. This work has been conducted at the University of Texas and was made possible through the cooperation and contributions of many people. Among those whose assistance the author gratefully acknowledges are Prof. P. M. Ferguson, Chairman of the Civil Engineering Department, and Prof. R. F. Dawson, Director of the Bureau of Engineering Research, at the University of Texas.

The 8B13, 6I12.5 and 6I17.25 rolled sections used in this program were donated by Austin Brothers of Dallas, Tips Engine Works of Austin and Mosher Steel Company of Dallas, respectively.

The services of R. B. Reilly of AISC, Dallas, in locating donors for the rolled sections are greatly appreciated.

Thanks are also due to the staff of the Civil Engineering Department and the Bureau of Engineering Research for their invaluable help.

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Appendix I

SECTION PROPERTIES

The actual thickness and size of rolled sections are usually different from the values given in steel handbooks. In order to facilitate the correlation of the

Table 3—Properties of Rolled Sections

		8B13			6I12.5		6I17.25	
			Measured					
Item	Units	Handbook	Lehigh	Texas	Handbook	Measured	Handbook	Measured
A	in^2	3.83	4.01	3.70	3.61	3.67	5.02	5.10
d	in	8.00	8.06	8.04	6.00	6.02	6.00	6.06
b	in	4.00	4.031	4.055	3.33	3.24	3.565	3.56
t	in	0.254	0.263	0.235	0.359	0.373	0.359	0.365
w	in	0.230	0.237	0.223	0.230	0.221	0.475	0.465
I	in^4	39.5	42.0	38.0	21.8	22.4	26.0	27.46
S	in^3	9.88	10.42	9.45	7.3	7.44	8.7	9.06
Z	in^3	11.38	12.01	11.00		8.54		10.96
f			1.152	1.163		1.149		1.210
G_{yf}	k/in^2		41.8	41.5		38.5		38.0
G_{yw}	k/in^2		47.1	43.4		40.0		38.65

Texas and Lehigh programs the measured (and calculated) section properties of 8B13, 6I12.5 and 6I17.25 are given in Table 3, together with the yield point for the flange and web material.

Discussion by Alfred E. Pearson

The author asked the discusser to prepare an estimate from a fabricator's point of view using the working drawings for the test specimens, that would reflect the relative cost of each type of knee tested. This has been done and the relative estimated fabrication cost for each specimen is shown in Table A.

The relative figures given in Table A include the labor cost of all operations involved in the fabrication of the specimens, not merely the cutting and welding time shown in Fig. 1 for the specimens tested at Lehigh University. To provide a tie-in with the Lehigh specimens the cost of fabricating Lehigh Specimen A was estimated and was found to be less than the fabricating cost for Texas Specimens A and E; however, the difference was only several cents. If material costs were included in the estimate the relative arrangement of the various specimens, costwise, would no doubt change position. It should also be noted that some of the Texas specimens were made of 6 I at 12.5 while others were made of 8B13 sections. Where specimens were identical except for the section used the 8B13 was somewhat more expensive primarily because more welding was required by the deeper beam.

Considerations other than cost but which affect cost have been noted that are of interest to fabricators. These concern quality of material and workmanship and a factor reflecting the quality of the material used has been noted in comparing the results obtained by the Lehigh and Texas Programs. The plain 8B13 tested at the University of Texas was noticeably less rigid and its maximum moment was approximately 10% less than a similar beam tested at Lehigh University whereas the calculated curve fell between the two curves drawn from test data. This condition was illustrated in Fig. 21, and probably represents a normal variation in different beams as rolled. Of course, the fabricator has no particular control over such discrepancies, but it is suggested that a curve similar to those shown must be developed to show the worst condition that might result before a fabricator will be willing to undertake a job primarily incorporating plastic design features.

The lowest reported yield strength of the beams tested was 38 ksi but the minimum permitted by present specifications is 33 ksi. If a proposed "welding quality" steel specification is adopted by ASTM the minimum yield will be lowered to 32 ksi for the new steel. A curve based on test data taken on a beam with the minimum allowable yield should reflect the worst condition as the test presumably would reflect the combination of minimum yield and residual mill stresses.

Three specimens tested actually fractured to a certain extent. Two of these fractures, in Connections A and C, were attributed to weld failures and the other on Connection B was attributed to poor design. Actually, all three fractures occurred in comparable locations where an abrupt change in section and undoubtedly stress concentrations existed. The departure from the calculated stress as evidenced by gage No. 12 shown in Fig. 19 tends to bear this out. Then too, the only fracture that occurred in the Lehigh specimens, while not a weld fracture, was located in the same general area. A crack in Lehigh Connection P started at the overhanging end of the beam web and at the root of the lower beam fillet, extended about 2 in. into the knee and initiated cracks in the end stiffner plates.*

The failure on Connection A, illustrated in Fig. 24, was described as a "pull-out" type and as such cannot be attributed to poor workmanship on the part of the welder. This fracture occurred when a total tensile force of approximately 41 kips was acting on the tension flange. This force represented an average load of approximately 12,000 lb/in. of width of flange or approximately 6000 lb/in. of fillet weld. The working drawings showed the particular weld that "pulled out" was a $^3/_{16}$-in. fillet; thus, the total load on the weld at failure was $3^1/_2$ times the usual safe allowable load of 1800 lb/linear in. used in conventional design practice for this weld size. For Connection C the total tension flange force was approximately 51 kips resulting in a weld stress of about 17,000 lb/linear in. of $^1/_4$-in. butt weld at the end of the tension stiffner. Thus, in this case, the total load carried by the weld at failure was about 3.4 times the conventional safe allowable load despite the fact that stress concentrations undoubtedly existed and were not considered in the above analysis.

Table A—Comparative Estimated Shop Cost for Fabrication of Various Connection

Connection	*Relative Cost*
A (Lehigh)	1.000
A & E	1.054
S	1.116
B	1.221
C	1.272
R1 & R2	1.310
D	1.510
T	1.537
U	1.871
F	2.306

Alfred E. Pearson is Chief Welding Engineer of the Ingalls Iron Works Co., Birmingham, Ala.

* Illustrated in Fig. 24, "Progress Report No. 4: Part I, Connections for Welded Continuous Portal Frames," by Toprac, Beedle and Johnston, The Welding Journal, 30 (7) Research Suppl., 370-s (1951).

Transformation of Cr-Mo Steels During Welding

Cooling transformations of two chromium molybdenum steels under welding conditions including preheat

by W. R. Apblett, Jr., R. P. Dunphy and W. S. Pellini

ABSTRACT

The continuous cooling transformations of two chromium-molybdenum steels, one a nominal 1.25% Cr – 0.5% Mo and the other a nominal 2.25% Cr – 1.0% Mo, have been determined for austenitizing and cooling conditions similating an actual weld. These steels undergo primarily a bainitic reaction and the specific microstructural conditions which are developed depend principally on the austenitizing temperature and the degree of solution of the carbides.

Preheating these steels to temperatures as high as 600° F for the purpose of obtaining softer transformation products in the heat-affected zone results in a relatively minor decrease in the maximum hardness developed.

INTRODUCTION

STEELS used for high-pressure steam lines of power plants are primarily the Cr-Mo types which were developed for resistance to graphitization at high temperatures. In welding these steels it is desirable that the heat-affected zones transform primarily to ductile, high-temperature reaction products. In order to prevent the development of high hardness reaction products resulting from transformations at low temperatures the generally recommended practice involves both preheat and postheat treatments usually in the order of 400–600° F preheat, followed by a 1250–1350° F postheat. Such heat treatments are expensive and difficult to apply to practical pipe-line systems.

The extent to which the various thermal treatments applied in practice actually produce the desired metallurgical effect has been subject to considerable debate. This investigation was aimed at studying the transformational behavior of these steels so as to provide needed basic information.

From experimental considerations, transformation characteristics are most conveniently studied isothermally and the literature contains copious references to the isothermal decomposition of numerous steels. The application of isothermal transformation data to the study of the hardenability of the heat-affected zone (which depends upon transformational behavior during continuous cooling) has met with limited success. This is due to the fact that many factors influence the rate of austenite decomposition, the most noteworthy of which are (*a*) chemical composition of the austenite, (*b*) austenite grain size, (*c*) degree of heterogeneity and (*d*) nucleating particles such as undissolved carbides and inclusions. In the continuous cooling transformation of the weld heat-affected zone each of these factors may vary between wide limits depending on the type of steel and the peak temperatures which are attained during the short times that various positions of the heat-affected zone remain within the austenite range.

Studies of transformations resulting from the short time austenitization of welding cycles have been made possible by a method which has been described previously.* This method has been applied to the study of the continuous cooling transformation during welding of two chromium-molybdenum steels with which this report is concerned. Weld experiments utilizing a range of preheat temperatures were conducted to evaluate the practical inferences of the transformation data.

EXPERIMENTAL PROCEDURE AND RESULTS

Materials

Material from a 1.25% Cr – 0.5% Mo steel pipe ($8^5/_8$-in. OD by 0.837-in. wall thickness) and a 2.25% Cr – 1.0% Mo steel pipe ($6^5/_8$-in. OD by 0.750-in. wall thickness) was used for this investigation. The chemical compositions are given in Table 1.

Table 1—Chemical Composition of Pipe Steel

	Alloy	
	$1^1/_4$ Cr	$2^1/_4$ Cr
C	0.09	0.12
Mn	0.48	0.39
Si	0.63	0.22
Ni	0.10	0.12
Cu	0.01	0.12
Cr	1.22	2.39
Mo	0.55	0.98

W. R. Apblett, Jr., and **R. P. Dunphy** are metallurgists in the Metal Processing Branch, Metallurgy Division, Naval Research Laboratory, Washington 25, D. C. **W. S. Pellini** is the Head of the Metal Processing Branch, Metallurgy Division, Naval Research Laboratory, Washington 25, D. C.

Presented at the AWS National Fall Meeting, Cleveland, Ohio, Oct. 21, 1953.

* Apblett, W. R., Poole, L. K., and Pellini, W. S., "The Continuous Cooling Transformation of Weld Heat-Affected Zones," THE WELDING JOURNAL, 31, p. 421-s (1952).

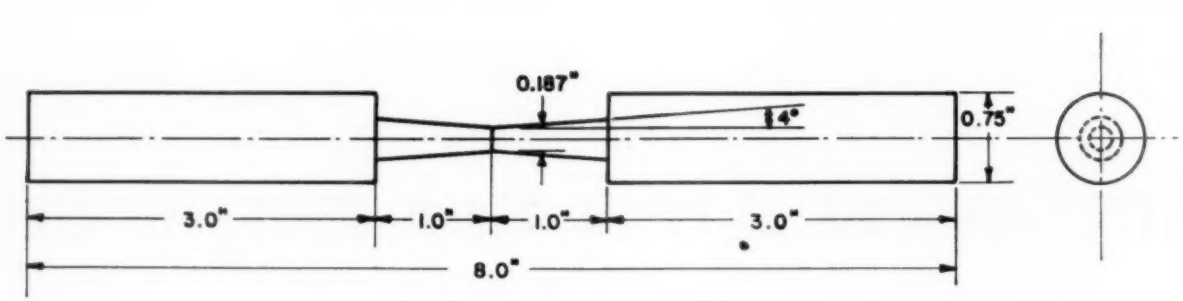


Fig. 1 Taper-bar specimen

The electrodes were designed to deposit weld metals with nominal composition of 2.0% Cr – 0.5% Mo (for use on the 1.25% Cr – 0.5% Mo steel) and 2.25% Cr – 1.0% Mo (for use on the 2.25% Cr – 1.0% Mo steel). All of the electrodes were low-hydrogen types.

Welding Technique

Fully automatic arc-welding equipment was used to deposit a 6-in. length of weld on a test section of pipe using $^5/_{32}$-in. electrode. The arc current and voltage were recorded and the arc travel speed was maintained constant by a motor driven carriage. The welding conditions were 180 amp, 25 v and 6 ipm arc travel speed which corresponds to an energy input of 45,000 joules/in.

Transformation Studies

The experimental procedure for studying the transformations which occur in a weld heat-affected zone utilizes a synthetic weld specimen of the dimensions shown in Fig. 1 (hereafter to be referred to as a taper-bar specimen). A controlled heavy current is passed through the specimen to cause rapid heating and melting of the least section. The physical dimensions of the taper bar specimen are such that any one specific location in the specimen will experience essentially the same thermal cycle as a corresponding location in an actual weld heat-affected zone. Therefore, all that is required to produce a continuous cooling transformation diagram for a specific energy input is to quench taper-bar specimens at various times after fusion and metallographically determine the progress of transformation in the various zones. The equipment for fusing and quenching these specimens is shown schematically in Fig. 2.

Figure 3 presents a series of photomicrographs illustrating the progress of transformation in the $1^1/_4$% Cr material of a position in the heat-affected zone that reached a peak temperature of 1800° F. Figure 4 shows the continuous cooling transformation diagram for this material constructed by similar metallographic examination of various positions covering the entire simulated HAZ of the taper bar. The corresponding diagram for the $2^1/_4$% Cr material is shown in Fig. 5.

Simplified versions of these two diagrams are shown in Figs. 6 and 7. The distances from the fusion line

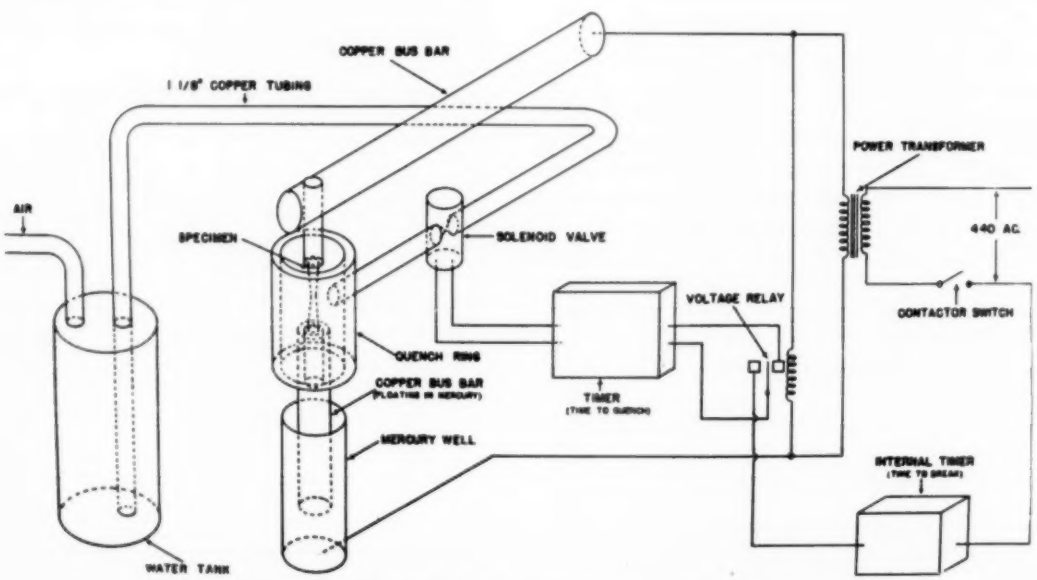


Fig. 2 Schematic drawing of taper-bar equipment

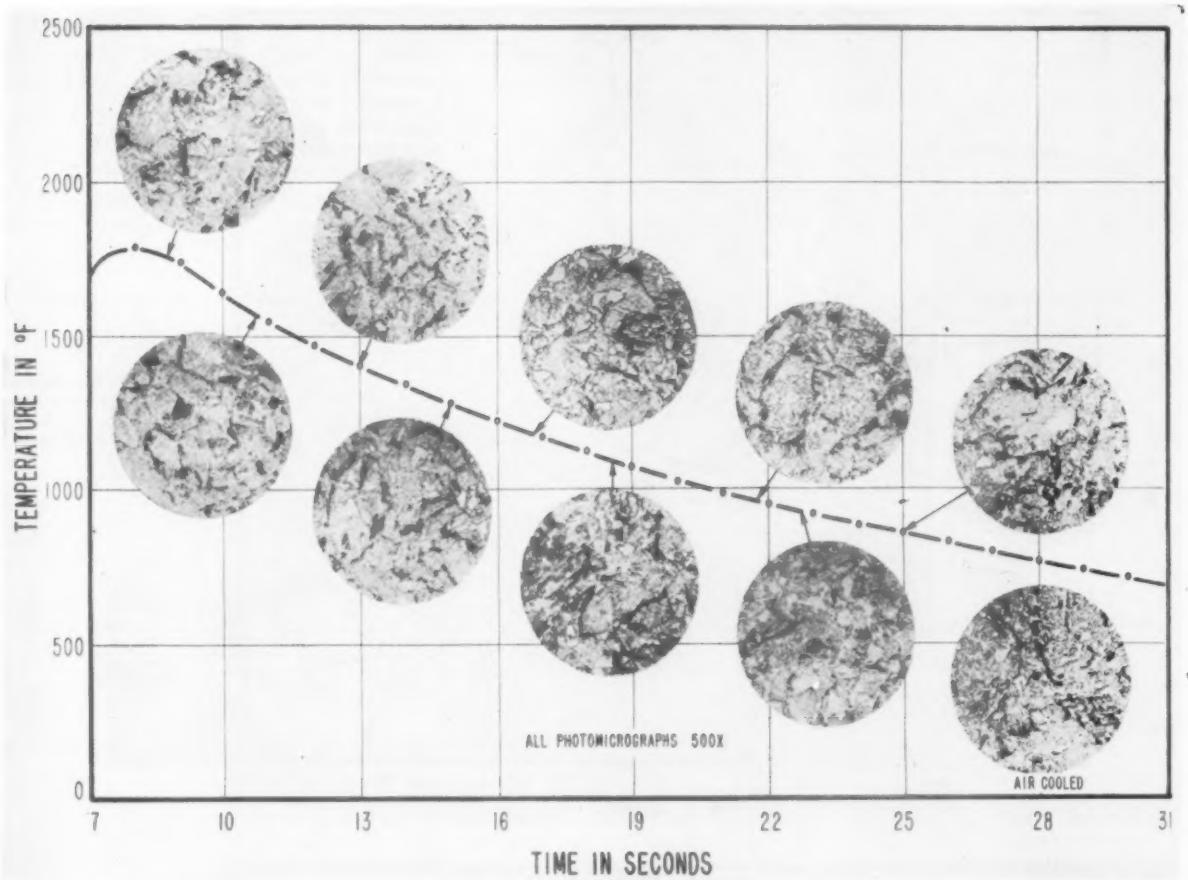


Fig. 3 Progress of transformation in 1¼% Cr material of a position in the HAZ that reached 1800° F

shown on the simplified diagrams refer to the bead-on-plate weld described previously.

In the previous work* conducted on HTS (0.15% C–1.22% Mn) it was relatively easy to determine the end of the various reactions metallographically; however, for these more highly alloyed steels, which undergo primarily a bainitic reaction, the metallographic determination of the end of a reaction is more difficult. It was therefore necessary to supplement the microscopic studies by hardness determinations. These data are shown in Figs. 8 and 9. In fact, the hardness data are sufficiently revealing that it would have been possible to develop a practical transformation diagram with relatively moderate microscopic examination to supplement the hardness data. For example, a hardness drop in the 1¼% Cr material occurs between 8.8 and 13.0 sec. for those regions which reached peak temperatures between the Ac_1 and 1800° F. This corresponds to the period of rapid formation of ferrite in these regions. A hardness drop corresponding to the bainitic reaction is not evidenced in regions which reached higher peak temperatures until 20–25 sec. After 31 sec. the bainite reaction is essentially completed as indicated by a close approach to the hardness levels in a bar which was cooled to room temperature without a quench interruption. Thus, the period of 20 to 31 sec. represents the time of bainite reaction for the regions which transform primarily to this product.

Preheat Studies

The limited amount of material available for this program necessitated the use of a unique technique for studying the effect of preheat on the hardness distribution in the heat-affected zone. A thermal gradient was established in a section of pipe approximately 18 in. in length by placing an oxy-acetylene ring burner around one end to create an 1800–2000° F hot zone, and water cooling the other end by means of a water jacket. After equilibrium was established a bead-on-plate weld was deposited along the length of the specimen using the aforementioned energy imput. This provided a single specimen in which the effect of preheats over a large temperature range could be determined from the hardness distribution across the heat-affected zones at various positions.

Figures 10 and 11 depict hardness variations in the heat-affected zone of a weld for various preheat levels from room temperature to 600° F for the 1¼% Cr and 2¼% Cr material, respectively. For purposes of comparison the effect of a 1350° F stress-relief anneal for one preheat condition of each weld is also included in these figures.

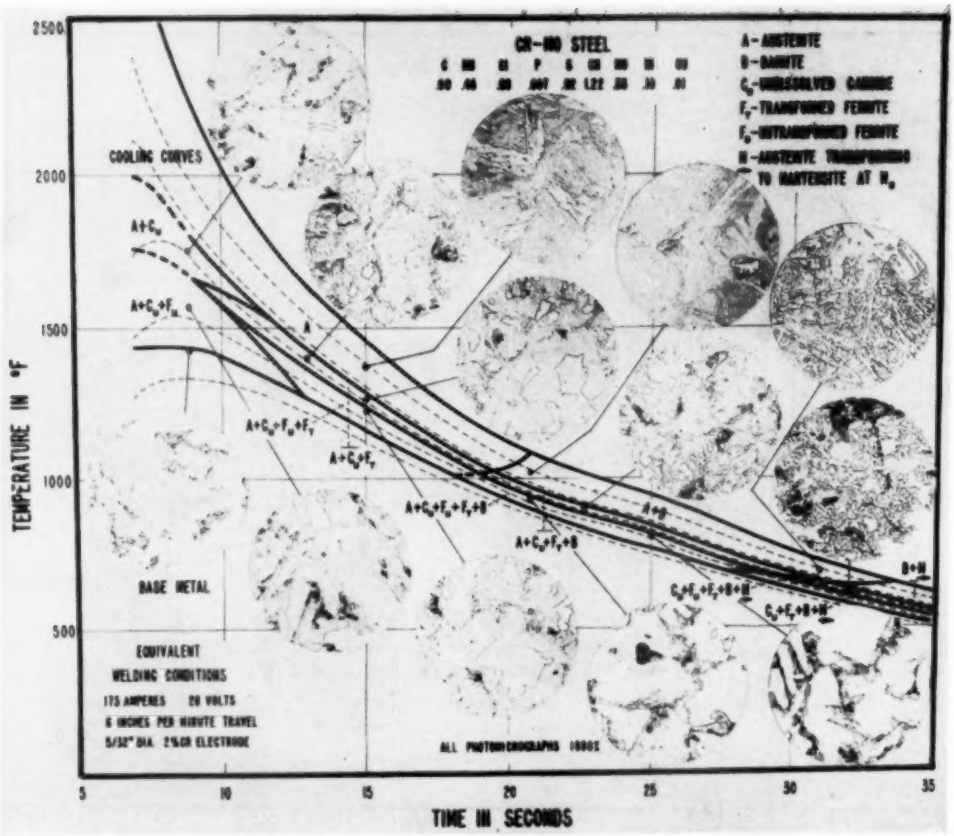


Fig. 4 Continuous cooling transformation diagram for 1¼ Cr – 0.5 Mo steel

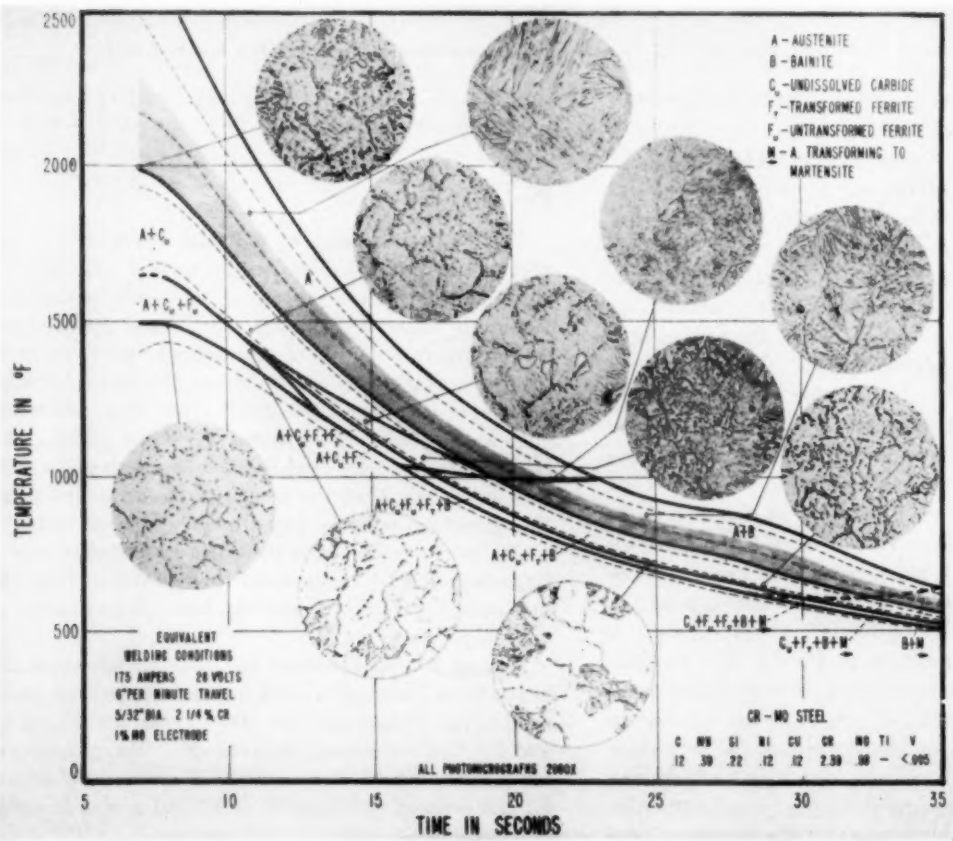


Fig. 5 Continuous cooling transformation diagram for 2¼ Cr – 1.0 Mo steel

This specimen will produce essentially the same thermal effect in the heat-affected zone as a uniformly preheated specimen. To illustrate this correspondence a section of $1^1/_4\%$ Cr pipe was preheated uniformly to 600° F and a section of $2^1/_4\%$ Cr pipe to 200° F. Similar hardness distributions were obtained in the heat-affected zones of the uniform and gradient method samples as shown in Fig. 12.

GENERAL DISCUSSION

1.25% Cr – 0.5% Mo Steel. Transformations which occur in the heat-affected zone of this steel are limited essentially to proeutectoid ferrite and bainite. In those regions which contain homogeneous (or nearly so) austenite, that is, regions which have been heated to peak austenitizing temperatures of 2000° F and above,

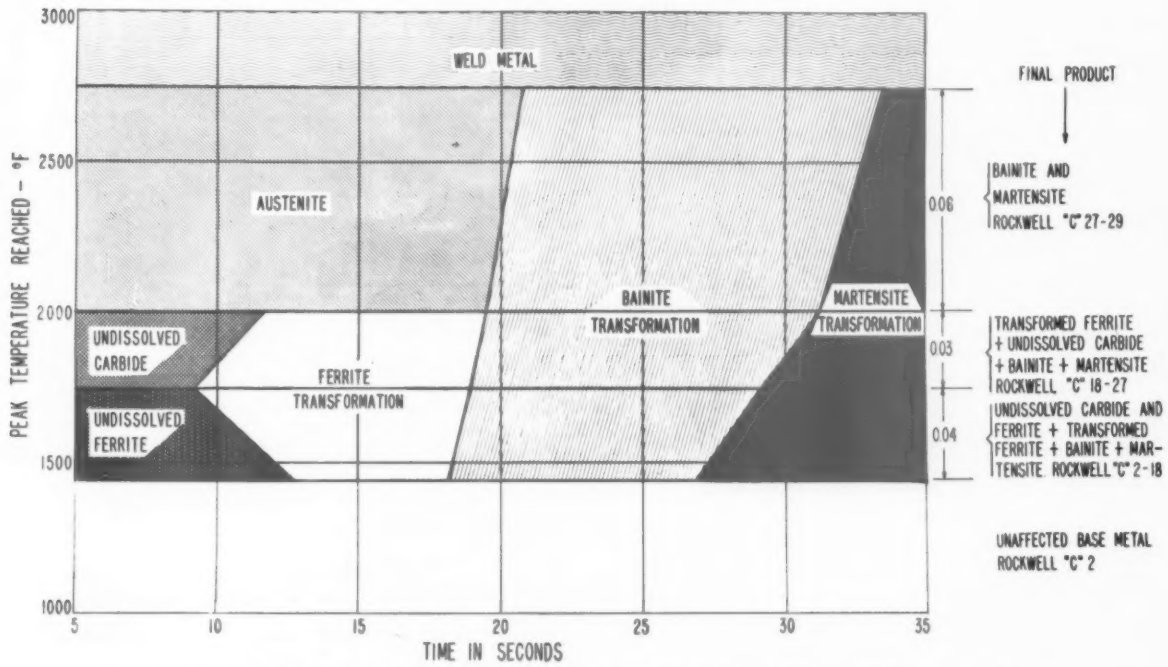


Fig. 6 Simplified version of diagram of Fig. 4 applied to actual weld heat-affected zone

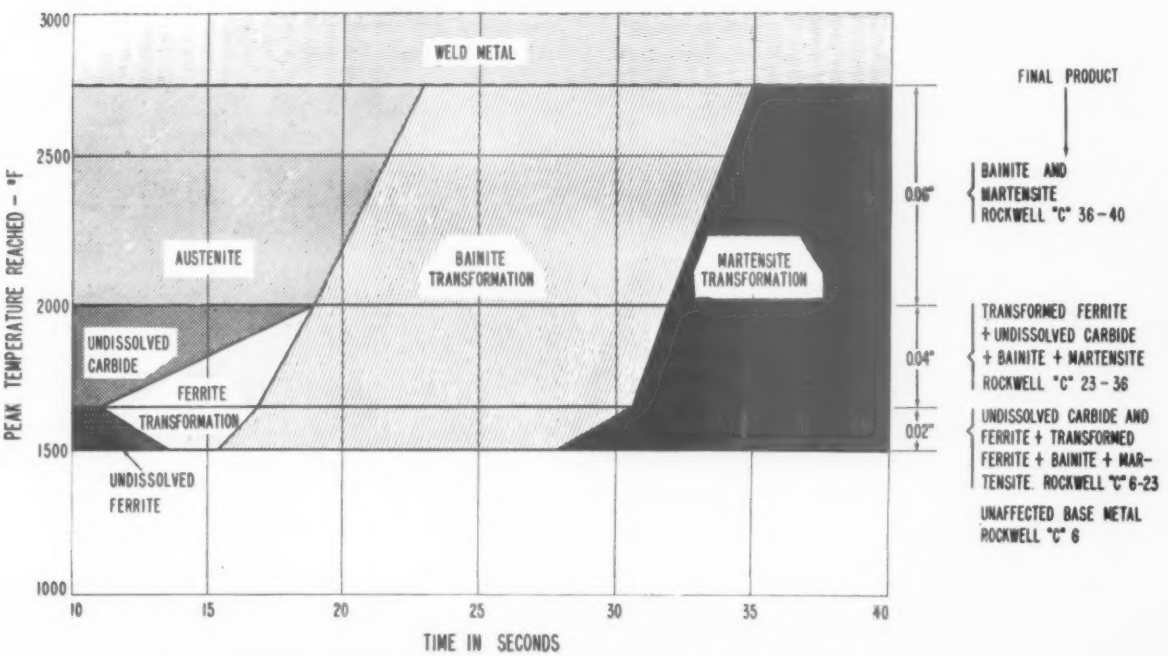


Fig. 7 Simplified version of diagram of Fig. 5 applied to actual weld heat-affected zone

the ferrite reaction is suppressed and only a bainitic reaction occurs. The bainite reactions starts at approximately 1000° F for those regions heated to 2000° F and is elevated slightly as the grain size increases and the austenite becomes more homogeneous as shown by the upward curve of the bainite start line on the diagram of Fig. 4. This reaction continues until a temperature of approximately 650° F is reached below which any austenite that remains will transform to martensite on continued cooling.

Regions which are heated to peak austenitizing temperatures between the Ac_1 (1440° F) and 2000° F contain undissolved carbides. The austenite formed at 2000° F and below is therefore of lower hardenability. Accordingly, these regions all show a certain amount of proeutectoid ferrite reaction in addition to the bainitic reaction products.

In that portion of the HAZ which has been heated in the range between the Ac_1 and Ac_3 (1440–1750° F) austenitization is limited to those regions immediately

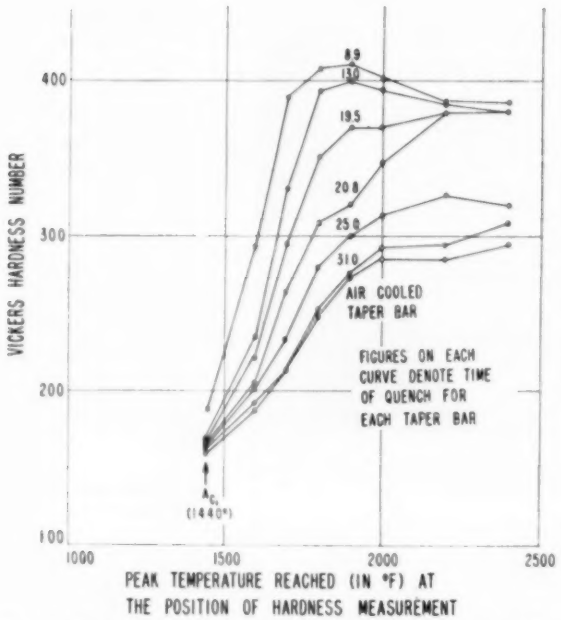


Fig. 8 Results of hardness surveys on time quenched specimens of 1¼% Cr material

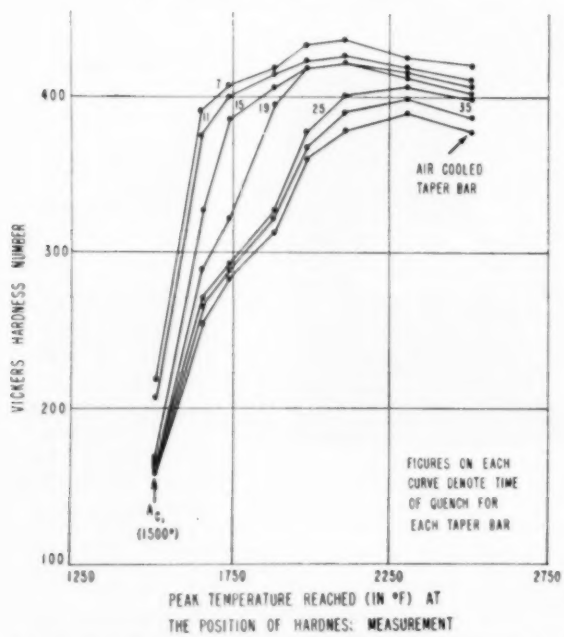


Fig. 9 Results of hardness surveys on time-quenched specimens of 2¼% Cr material

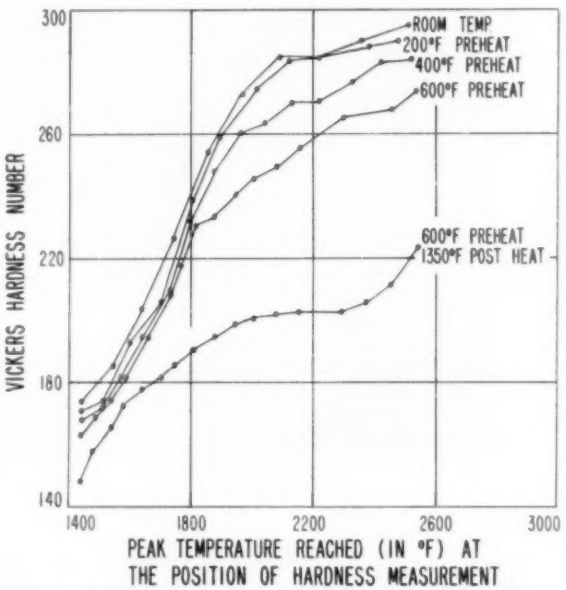


Fig. 10 Hardness distribution in 1¼% Cr HAZ as affected by preheat

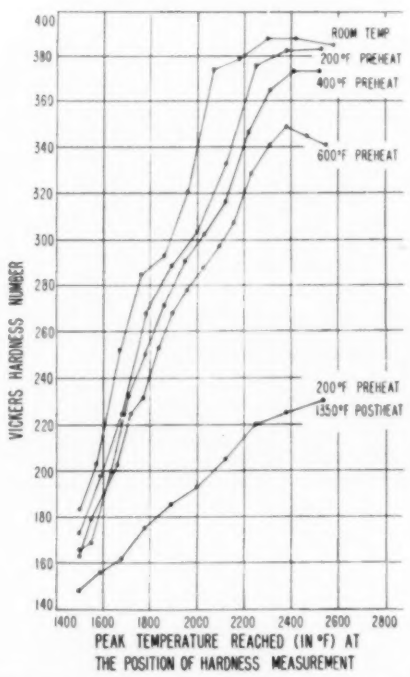


Fig. 11 Hardness distribution in 2¼% Cr HAZ as affected by preheat

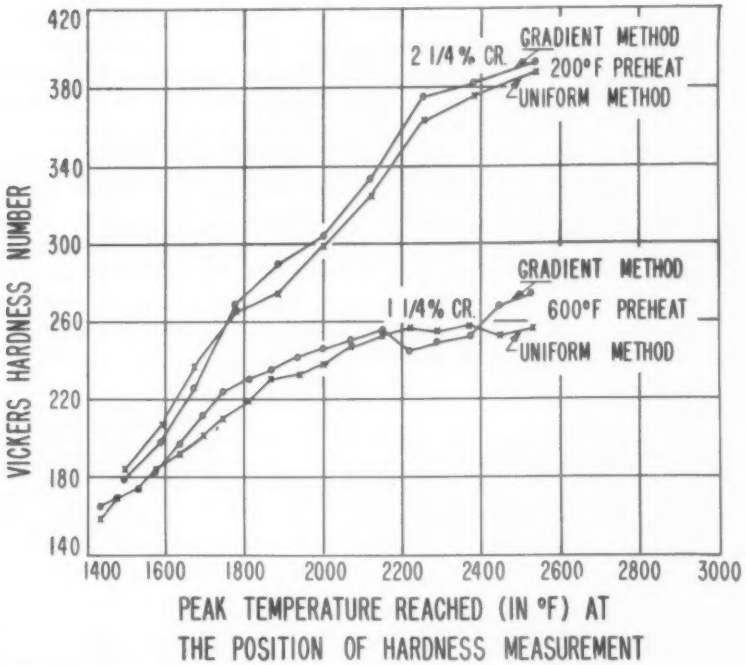


Fig. 12 Comparison of HAZ hardness obtained using uniform and gradient preheat methods

surrounding the carbides. At the lower level of this temperature range, i.e., the region that has been heated just above the Ac_1 temperature, a continuous network of austenite surrounding each ferrite grain results. A small amount of ferrite and bainite transform on cooling; however, the primary reaction in the austenite network is a martensitic one. While a study of the properties of such a structure was outside the scope of this investigation, a zone of continuous martensitic network should be considered potentially dangerous. A similar network of martensite was found in the HTS steel studied previously.

2.25% Cr – 1.0% Mo Steel. In general, the same basic trends are found in this steel as in the 1.25% Cr – 0.5% Mo steel. The increase in alloy content reduced appreciably the amount of proeutectoid ferrite formed on cooling and lowered somewhat the temperature of initial bainite rejection.

There are several interesting metallurgical phenomena associated with the steel. The carbide solution temperature has been indicated at 2000° F on the diagram of Fig. 5. Above this temperature there is shown a shaded porportion extending to austenitizing temperatures in the vicinity of 2300° F. This represents a two-phase region which is considered to contain austenite and delta-ferrite. Apparently when the carbide phase dissociates, there exist regions of sufficiently high-alloy content to close the gamma loop. The high-alloy concentration at the site of the original carbide region results in alloy diffusion into the surrounding austenite increasing the size of the delta ferrite regions. Under the microscope it appears as though the carbides increased in size in the vicinity of 2000° F. The size of the carbides at 1700° F as compared to that of the delta ferrite patches at 2000° F is shown in Fig. 13.

Effect of Preheat

The metallurgical purpose of preheating, as stated previously, is to produce softer transformation products in the heat-affected zone of the base metal. It has been shown that the Cr-Mo steels investigated undergo primarily a bainitic reaction of relatively high hardness. Therefore, if preheat is to have a beneficial effect, it must prolong the time the steel has to transform at temperatures above the bainite range so as to promote ferrite and pearlite transformation.

The extent to which preheating as high as 600° F can be beneficial in eliminating the bainite reaction has been shown in Figs. 10 and 11. These figures indicate that even a 600° F preheat is not effective in that it

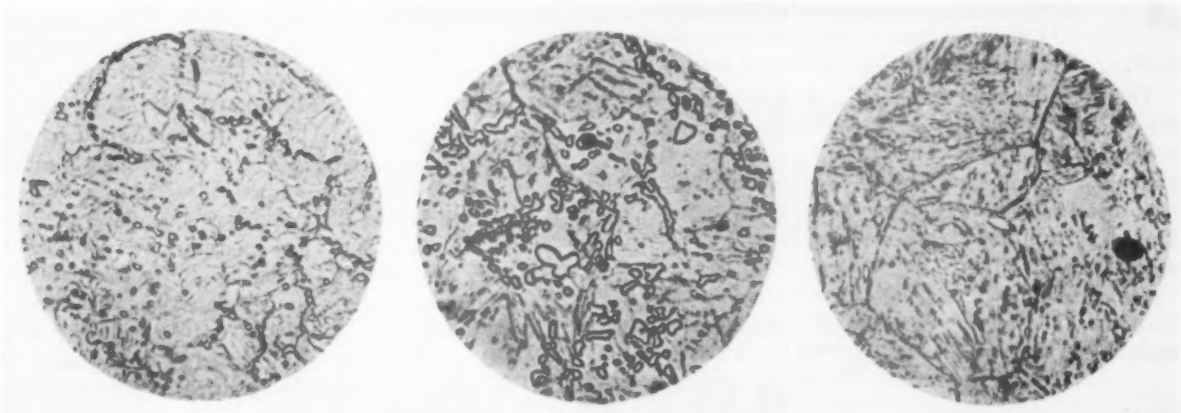


Fig. 13 Illustrating formation of delta ferrite (center photomicrograph) in 2¼% Cr material

will drop the maximum hardness in the heat-affected zone less than 40 Vickers hardness numbers for both steels investigated. From consideration of the time-temperature relationships of the continuous cooling transformation diagrams it appears that preheats of approximately 1000° F would be required. This, in effect, represents holding the metal at a temperature such that isothermal transformation to ferrite and pearlite structures will occur. Such preheat conditions do not appear to be practical. This should not be interpreted to mean that preheats of 600° F or less are not useful; certainly under high restraint conditions preheat quite frequently will eliminate cracking of root passes. However, it is concluded that preheating of these materials provides no beneficial metallurgical effects.

CONCLUSIONS

The continuous cooling transformations of two chromium-molybdenum steels, one a nominal 1.25% Cr – 0.5% Mo and the other a nominal 2.25% Cr – 1.0% Mo, have been determined for austenitizing and cooling conditions simulating an actual weld. These steels undergo primarily a bainitic reaction and the specific microstructural conditions which are developed depend principally on the austenitizing temperature and the degree of solution of carbides. A steel with a nominal composition of 2.25% Cr – 1.0% Mo will contain delta ferrite when rapidly austenitized to temperatures above 2000° F. This is due to the formation of delta ferrite when the carbide phase dissociates producing localized regions of high-alloy content.

Preheating of these steels for the purpose of obtaining softer transformation products in the heat-affected zone is not successful. Preheats as high as 600° F result in a relatively minor decrease in the maximum hardness in the heat-affected zone (40 VHN or 4RC).

ACKNOWLEDGMENTS

The authors wish to acknowledge the sponsorship of this investigation by T. Griffin of the Welding Code of the Bureau of Ships. The authors also wish to thank Dr. O. T. Marzke, Head of the Metallurgy Division of the Naval Research Laboratory, for his advise and assistance. They are further indebted to Mr. D. O. Buker for his assistance in much of the experimental work.

Hot Cracks in Weld Metal

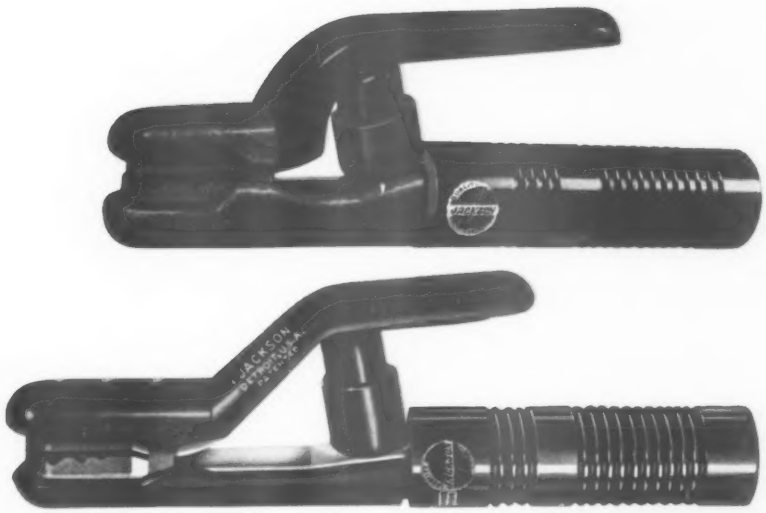
by K. Kautz

A GERMAN standard (DIN 50129) has been issued to assess the susceptibility of filler metal to hot cracks. Resistance to hot cracking is the property of a weld metal to remain free from cracks during cooling. Two double-fillet-weld specimens are used.

The first specimen is for mild- and low-alloy steel filler metal. A plate 1/2 in. thick, 4 in. high is placed in the center of a plate 1 3/4 in. thick, 3 1/8 in. wide. Both plates are 4 3/4 in. long and are of a steel in which the filler metal must be crack resistant. The edge of the 1/2-in. web plate, if flame cut, must be ground to fit well against the flange plate. The filler rod or electrode is 5/32 in. diameter. The fillets are deposited in the flat position. The plates are tacked together at both ends on the side opposite the first weld. A heavy concave fillet is deposited on the first side. While the plates are still hot, a smaller concave fillet is deposited on the other side in a direction opposite to the first fillet. Both fillets are deposited without backing or oscillation of the electrode. After the second fillet has cooled, it is examined for cracks with a magnifying glass. A few light hammer blows may be struck on the web to open any cracks and render them more easily visible. The length of the cracks is quoted as a percentage of the length of the weld. The number of transverse cracks also is reported.

The second specimen is for austenitic filler metal and consists of plates 1/2 in. thick, 4 3/4 in. long. The web plate is 2 in. high, the flange plate is 3 1/8 in. wide. The web plate is made of low-alloy steel; the flange plate is a plain carbon steel. The test procedure is the same as for the first specimen. The first specimen is called the Railway specimen, the second is the Navy specimen. When the standardizing committee first met in 1950, a specimen consisting of two round bars was considered. The bars are parallel and beads are deposited in the space between them. The bars are of steel having a tensile strength of 71,000 psi. The committee later omitted the round specimen from the specification as too severe. It is taken for granted in the two fillet-weld specimens that the web must fit accurately against the flange to secure reliable results.

Abstract from *Schweissen und Schneiden*, **5**, 352 (September 1953). (Abstracted by Dr. G. E. Claussen.)



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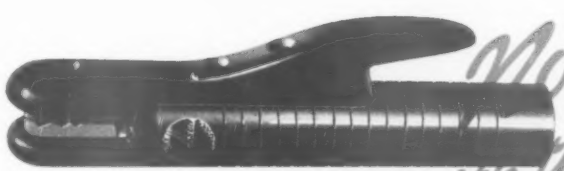

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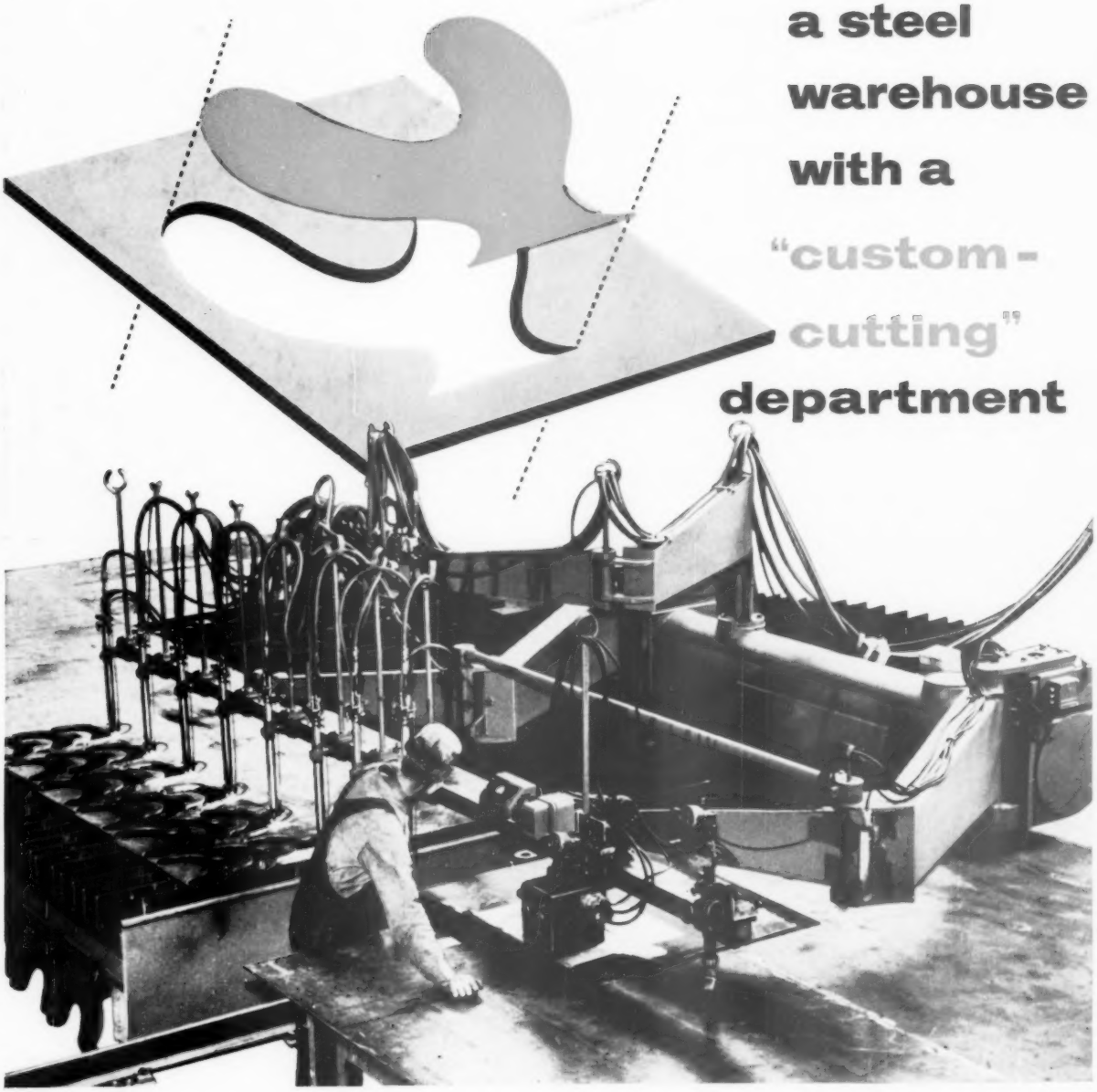

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